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THE INFLUENCES OF CAVE TOURISM ON CO_2 AND TEMPERATURE IN BAIYUN CAVE, HEBEI, CHINA[1]

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ABSTRACT

Baiyun Cave in Hebei Province is one of the main show caves in North China. The speleothem landscape is wonderful, but strongly weathered. In order to set up the relationship between visitor flow and CO_2 content and temperature, these parameters were measured at observation sites No.1 and No.2 in the tourist peak period of May Day Holiday from May 1 to May 7, 2000, and general tourist season August and October, 2000. The results show that visitor flow strongly affects the fluctuations of cave CO_2 content and temperature, that the cave topography and dimensions affect the accumulation and diffusion of CO_2. Variation of air temperature in the cave was shown to be attributable to the visitors.

Keywords: Baiyun Cave, visitation, CO_2 concentration, temperature

Past work

The activities of visitors have an effect on the cave environment as well as the natural material and energy exchanges between the inside and outside of caves. Visitation causes speleothems to be seriously weathered and changed in their original colours, and sometime to become completely damaged or destroyed. The effect of speleo-tourism on the environment and speleothem scenery in show caves has been studied in China and throughout the world (Cigna and Forti, 1989; Cigna and Sulas, 2000; Song, 1994; Song et al, 1997).

The results have shown that cave air temperature and the CO_2 concentration are directly correlated to the visitor flow, while the relative humidity of cave air is inversely correlated to it (Cigna & Forti, 1989; Song et al. 1999; Zhang,et al. 1997), especially in the warm season, and the night is not long enough to recover the equilibrium values (Bertolani and Cigna,1993). Specifically Cigna et al. (1996) showed

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that natural factors caused CO_2 concentration changes in the Grotta Grande del Vento, Italy. Villar et al.(1986) constructed a model to predict the temporary variations of CO_2 concentration due to the presence of visitors based on their experiments in the Altamira Cave, Spain.
This paper stresses on the effect of visitor flow on the cave environment in Baiyun Cave in north China.

Brief Introduction of Baiyun Show Cave
Baiyun Cave is located in Lincheng County, Hebei Province, China (Fig.1). The altitude of cave entrance is 157 m. The cave has no natural entrance: it was opened by local people when they quarried limestone on the hill for cement production in 1988. Since Baiyun Cave was opened to the public in 1990, over 2 million people have visited it. Now its annual visitor number is stable at 200,000 per year and it has become one of the main show caves in north China.
Baiyun Cave is about 500 m long, with about 2000 m of visitor trails. It includes five halls or rooms (Table 1): Paradise Hall is the largest one with an area of 2,170 m^2 and volume of 43,400 m^3 and Maze Hall is the smallest. Maze Hall and the Dragon Hall have an average width of less 2 m. The cave system consists of three levels. Paradise Hall is on the upper level, Maze Hall on the middle level and the Dragon hall is on the lowest level. All three levels are connected by a vertical shaft.

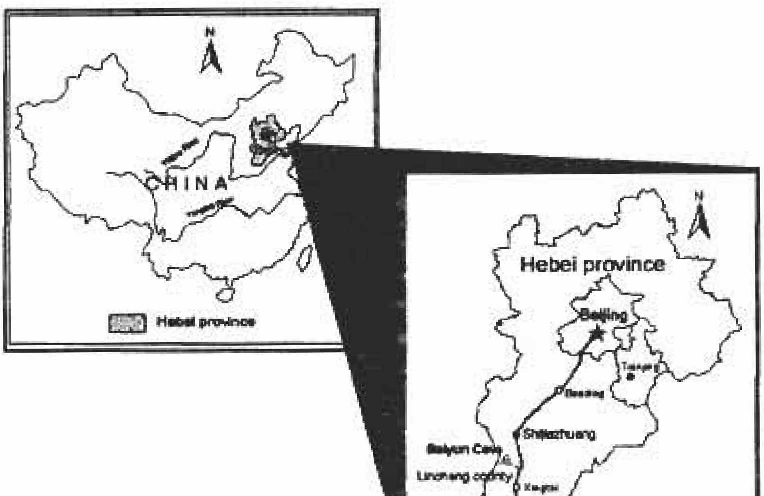

Fig. 1 - Location map.

Table 1 Characteristic of Baiyun Cave, Lincheng, Heibei, China

Cave hall	Length (m)	Average width (m)	Average height (m)	Volume (m^3)
Earth Hall	35	24	18	15120
Paradise Hall	95	22	20	43400
Hell Hall	22	10	12	2640
Dragon Hall	275	1-5	10	7500
Maze Hall	220	0.5-1.5	-	-
Total	647	-	-	-

No river flows through Baiyun Cave, but there are 3 small natural ponds with an average depth of about 0.5 m. The largest pond, with less than 10 m^3 of water, is located in lowest part of Dragon Hall and is connected to the water table. Airflow in cave is very weak, ranging from 0.05 to 0.07m/s in the narrowest passages. The highest weak speeds reach 0.15m/s. In the dry season, there is scarcely any drip water in Baiyun Cave, and there are only several drips in the Dragon Hall all around the year. In the wet season (especially in July and August), drip water is abundant during and just after heavy rainfall, especially in the Earth Hall and Paradise Hall where the thickness of cave roof is rather thin, somewhat less than 10 m.

Most of thespeleothems in Bayun Cave were strongly weathered under closed condition before the cave was opened to the public. The outer crusts of many draperies, stalactites, stalagmites, columns have been weathered to a white powder. For example, the surface of a column in Paradise Hall has been weathered to a thickness of 1.5 cm. On the other hand, many small speleothems such as stone grapes, pearls, hanging pipes, shields and helictites are growing over the weathered surfaces Probably this weathering is due to condensation corrosion (Cigna & Forti, 1986). This phenomenon is the main characteristics of Baiyun cave (Song et al., 2000).

Surveying Periods

Surveying periods were arranged during the tourist peak period for the May Day Holidays from May Day to May 7 and in the lowest period in August caused by the road construction during the year 2000. The main surveys were carried at No.1 and No.2 sites (Fig.2).

Site No.1 islocated in the centre of Paradise Hall which has a volume of over 43,400 m^3. It is on the left side of the hall slope. The slope consists an upper slope of 15^{O} and a lower slope on the right. There is a vertical way to connect the second and third levels of the cave system.

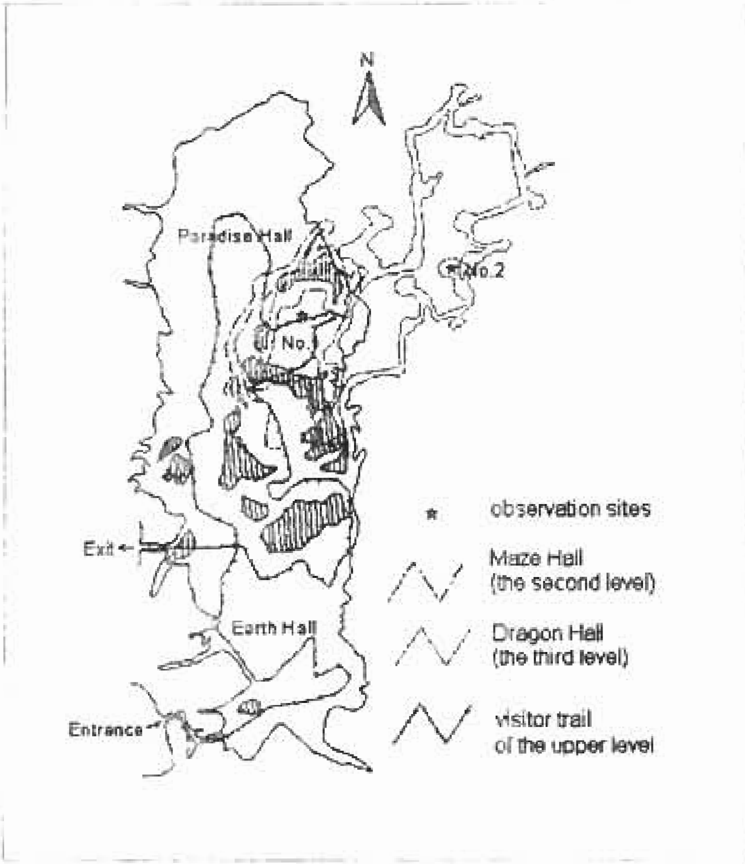

Fig. 2 - The plan of Baiyun Cave, China

Site No.2 is in a small chamber in Dragon Hall. This chamber has a volume of about 100 m[3] and is 2-3 m wide, 14 m long and 3-6m high, with a steep ladder to the upper room, 5 m high with a dip of 70° and 5 m high links the lower Treasure Room. Its exit is a narrow gate about 1 m wide and 1.7m high, then one must ascend another steeper ladder to the upper room. Generally, visitors enjoy the beautiful scenery in the chamber for 3-5 minutes, but during the peak hours, they may have to wait there for at least 10-20 minutes.

The number of visitors was recorded for 10 minutes at the two sites. A Gastec CO_2 System was employed to measure cave CO_2 concentration; the temperature was measured by Portable Digital Thermometer each half an hour from 8:30 to 18:00, each 1 hour from 18:00 to 20:00, then each 2 hours until 8:00, the next day.

Results and Discussion

Influence of visitors on CO_2 content

The visitors' breath is an important source of cave CO_2 (Fig. 3 and 4). The trend of CO_2 concentration is very similar to that of visitor flow.

On May 1, the total number of visitors that passed close to Site No.1 was 5853 persons. During this day CO_2 content increased from 600 ppm at 8:30 (when the cave just opened) to the peak of 4400 ppm at 16:30. At Site No.2, the total number of visitors was 4975 and CO_2 concentration increased from 1000 ppm at 8:30 to its peak of 5800 ppm at 14:00. On May 2, CO_2 concentration reached a maximum value of 7000 ppm at 16:00 at Site No. 2, when the total number of visitors was 5223 persons. Such peak concentrations of CO_2 higher than 5000 ppm lasted for one hour on May1, and for 5 hours on May 2.

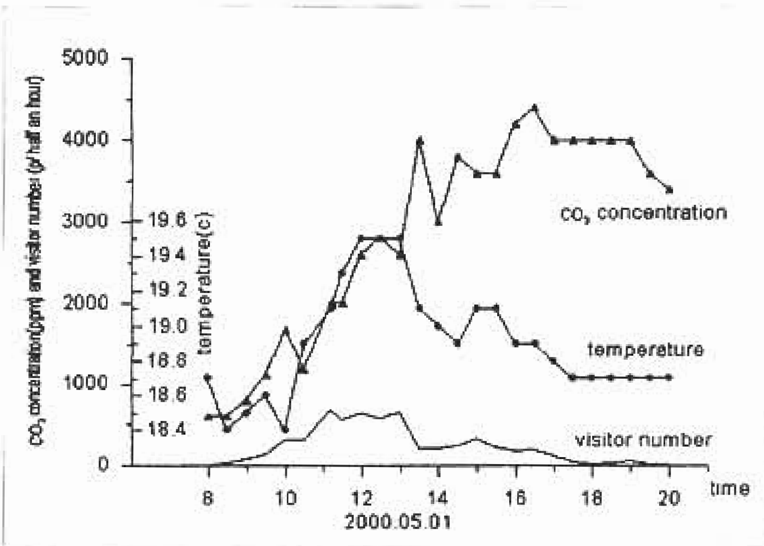

Fig. 3 - Variations of cave CO_2 concentration, air temperature and visitor flow at Site No.1, Baiyun Cave, Hebei, China

CO_2 concentration in caves decreases and returns to the previous level through air interchange between the outside and inside of the cave. If it cannot return to the previous level overnight, CO_2 will accumulate during the next tourist day. Fig.4 shows that at Site No.2 after overnight interchange, CO_2 concentration still was 2600 ppm at 9:00 (no visitors) on May 2. This value was much higher than the1000 ppm at 8:00 on May 1st, 2000.

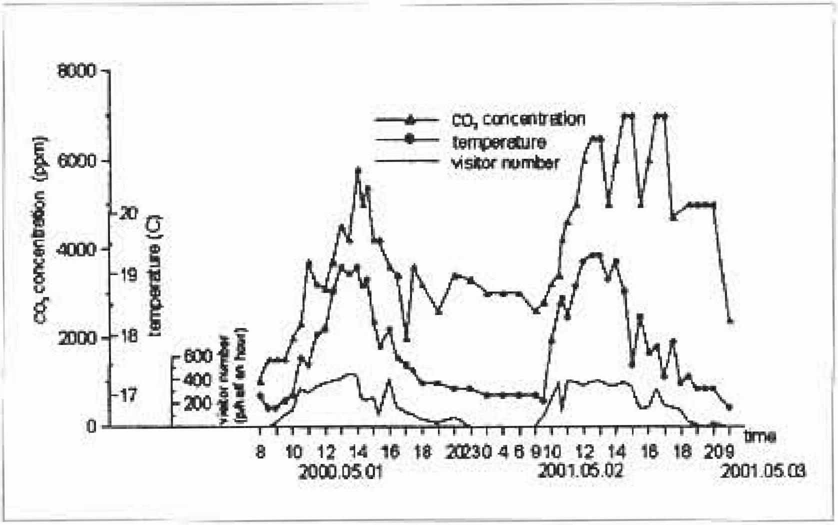

Fig. 4 - Variations of cave CO_2 concentration, air temperature and visitor flow at Site No.2, Baiyun Cave, Hebei, China

In addition we made some observations in days of low season; that is, on Aug 12, 2000 at Site No.1 and on Oct 1, 2000 at Site No. 2. The results show that the maximum CO_2 concentration was corresponds to the daily visitor number (Fig. 5 and Fig.6).

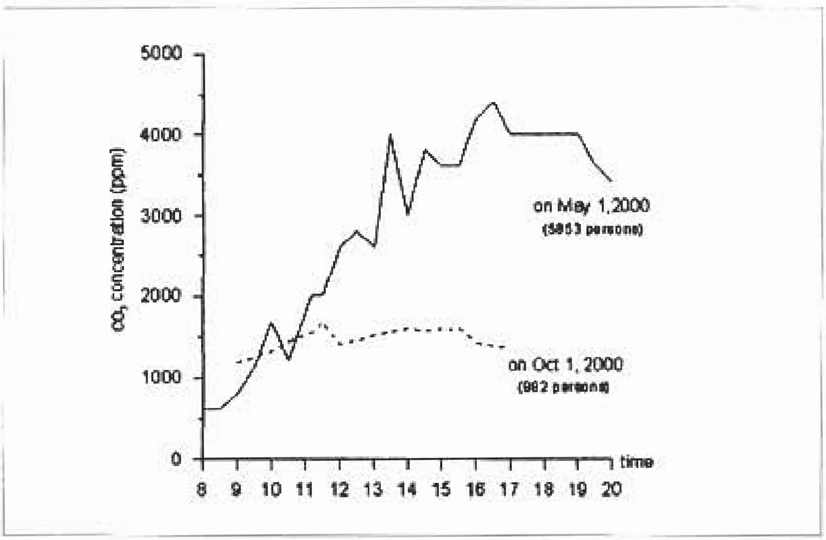

Fig. 5 - CO_2 variations at site No.1 on May 1 and Oct. 1, Baiyun Cave, Hebei

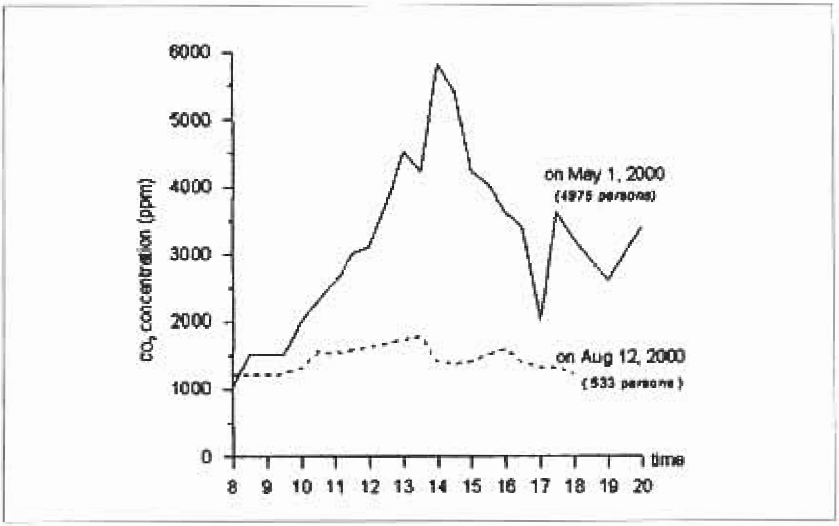

Fig. 6 - CO_2 variations on May 1 and August 12, 2000 at Site No.2, Baiyun Cave

Influence of visitors on air temperature

The human-related energy in show caves is mainly affected by two causes: 1) cave lights and facilities and 2) visitors. Villar et al. (1984) made some field experiments in Altamira Cave, Spain, and the results show that the range of heat released by a standing visitor is between 82 W and 116 W while a walking visitor releases about 170 W. So the annual energy input (E) can be calculated by the following formula:

$$E=170*t*3600*N$$

where: t is average visit time in hours and N is the annual total number of visitors. The visitor number to Baiyun Cave is about 200,000 persons per year, and the average visit time for each visitor is about 50 minutes. According to the above formula, the total annual energy input E from visitors can be estimated as $1.02*10^{11}$ J/s (= 28 MWh) in Baiyun Cave. Adding the energy from the light system, the total annual energy input due to the tour activities is still higher.

It is obvious that visitors influence air temperature as the fluctuations of air temperature correspond with the number of visitors (Fig.3 and Fig.4). The largest variation of air temperature is from 18.1^{o}C to 19.5^{o}C at Site No.1 and from 16.8^{o}C to 19.1^{o}C at Site No.2. When visitor flow reaches its peak, the air temperature also becomes maximum and then decreases together with decrease in visitor flow. The background value is reached overnight.

Over 60% of visitors visit Baiyun Cave between 10:30 a.m. and 2:30 p.m. In the rush hour, visitors are more than 1000 persons per hour, and in the other hours they are less than 300-400 persons per hour. At Site No.1, air temperature hardly changed when visitor flow is under 400 persons per hour, whereas a visitor flow over 1000 persons per hour may increase air temperature by 0.7^{O}C.

Air temperature at Site No.2 is more sensitive to visitor flow than at Site No.1. Visitor flow of over 200 persons per hour might make air temperature increase 0.2 ^{O}C, and the maximum increase of temperature might be 1.0^{O}C at a visitor flow of over 500 persons per hour.

Influence of cave volume and topography on CO_2 concentration

The cave environmental setting in Baiyun Cave is very complicated. The different setting strongly affects on the accumulation and diffusion of CO_2.

Fig.5 shows that the room volume directly affects CO_2 accumulation. On May 1, although the total visitor number near the No.1 measuring site was 1000 persons higher than that at Site No.2, CO_2 content at Site No.1 was lower than that at Site No.2 during the daytime. The difference is caused by the difference of cave volume of two sites. Site No.1 is located in the centre of the Paradise Hall with a volume of 43,400 m^3. CO_2 released by the visitors diffuses throughout this big chamber so that the CO_2 concentration does not exceed 4000 ppm

On the other hand, Site No.2 is located in the centre of a small room with a volume of only about 100 m^3, and containing two bottle-neck entrances. Here, in the rush hour, many visitors are delayed for long time from 11:30 to 15:00. Nearly 50 persons are crowded into a small place for 10-20 minutes. CO_2 accumulated and reached the peak of 7000 ppm on May 2, 2000.

At Site No.1, the accumulation rate of CO_2 was slower than the visitor flow. Fig. 3 shows that the variation of CO_2 concentration lagged behind the visitor flow nearly 1-2 hours. It was very different at Site No.2 where the CO_2 released by the visitors was accumulated and stored in the small room for a long time, so the variation of CO_2 concentration and visitor flow almost varied synchronously.

In addition, cave topography also played an important role on the CO_2 variation after 14:00. When the visitor number started to decrease, CO_2 concentration at the two sites showed different variation trends. At Site No.1, CO_2 concentration decreased immediately, but at Site No.2, it continued to increase slowly before starting to decrease (Fig. 7). This phenomenon might be due to the difference in density between air and CO_2 (Song et al., 1999). At Site No. 2 the CO_2 heavier than air may flow to a lower cave system. At Site No the room is larger but without lower cave passages. When this hall has a high CO_2 concentration, the difference of density between air and CO_2 will not play a relevant role, and the high CO_2 concentration will last longer.

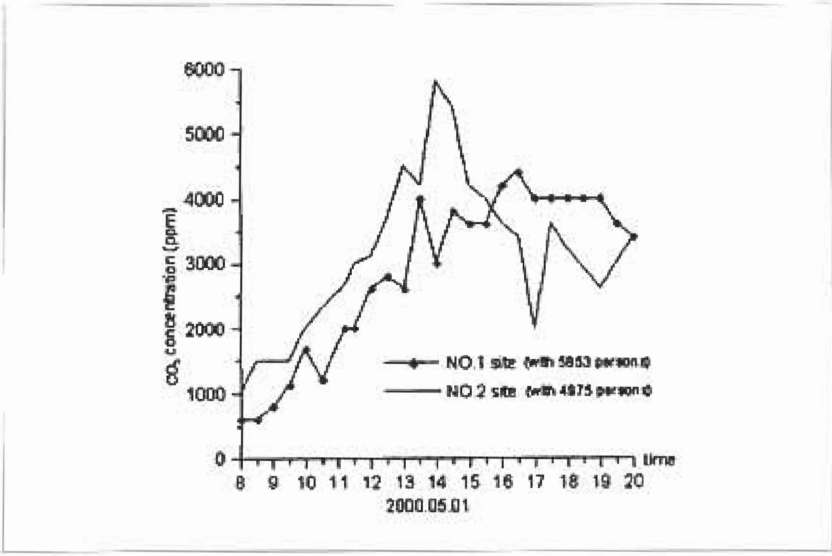

Fig.7 - Comparison of the variations of CO_2 concentration in Site No. 1 and 2.

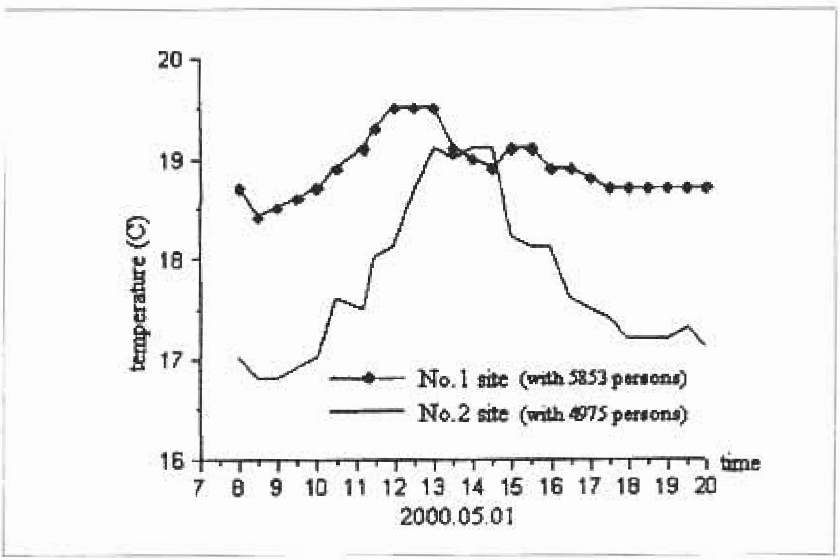

Fig.8 - Comparison of the variations of air temperature in Site No. 1 and 2.

Influence of cave topography on air temperature

Fig.8 illustrates that the influence of cave topography on air temperature is similar to that on CO_2 concentration. Although air temperature at Site No.2 is lower than temperature at Site No.1, the temperature variation at No.2 is more sensitive than that at No.1 to the visitor flow. The visitor and tourist facilities caused 2.4^{o}C temperature increase at No.2 and only 1.1^{o}C at the No.1.

Conclusion

The conclusions that may be drawn from these observations are as follows:

The intensity of visitor flow strongly affects the fluctuation of cave CO_2 content and air temperature;

Cave topography and dimensions control the rate and range of CO_2 concentration and temperature variations. They obviously affect the accumulation and diffusion of CO_2;

Due to the different density between air and CO_2, an accumulation of CO_2 in the lower part of the cave system may occur;

Under natural conditions, the cave has the self-cleaning ability to lower the CO_2 concentration, but in the case of human impact, such self-cleaning ability is greatly reduced;

Generally, when the increase of air temperature due to visitors is stopped, previous natural conditions are attained shortly after the end of tourists' visit.

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