Relationships among Cave Micrometeorology, Speleothem Growth and Surface Environment Revealed by Cave Monitoring Studies

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Cave monitoring study is carried out on account of cave environmental protection and, particular recently, precise interpretation of paleo climatic archives in caves. The objects of this study are to reveal the relationships among cave micrometeorology, speleothem growth and surface environment and to provide the useful scheme for interpretation of speleothem archives through cave monitoring in Japan and Indonesia where few cave monitoring studies have been conducted.

In Chapter I, we explain the condition of this study in development of cave monitoring studies and demonstrate aim of this study as above stated.

In Chapter II, results of geomorphological survey and cave monitoring in Hokkai Cave, where is discovered in 2006 in southwestern Hokkaido, northern Japan, is demonstrated. This chapter reports the results of speleological basic study of the cave's environment conducted during 2006-2009, including a geomorphological survey as well as monitoring of cave air temperature, airflow and ground water currents, and an interpretation of the speleogenesis. Hokkai cave is a zigzag, horizontal, 479.8 m long cave with two entrances. The cave floor is mainly covered with clay gravels and breakdown blocks. The underground river flows in the center of the cave. A dry riverbed, and many springs and dolines are observed around the cave. Some pure white stalagmites are present; they are possibly suitable for Asian Summer Monsoon reconstruction studies. Air temperature in the inner cave (> 15m from entrances) was stable throughout a year (7.5-7.7 ˚C), on the contrary, air temperature in the vicinity of the entrance was variable because of the influence of the outside air temperature. Inversion of airflow direction is driven by the air temperature gradient between the inside and the outside of the cave. When air temperature inside is warmer than outside,

air flows from Ent.U (upper) to Ent.L (lower) and from Ent.U to the inside. Whereas, when air temperature outside is warmer than inside, air flows from Ent.L to Ent.U and from the inner cave to Ent.U. These results coincide with previous studies. Inversion of airflow direction also affects the variation pattern of air temperature near the entrances. It appears that the underground river is usually dried up except sometimes after rainfall or snow melting.

In Chapter III, How affects air CO_2 fluctuation to speleothem growth rate in tropical area is studied in Petruk Cave, Central Java, Indonesia. After 1990s, speleothems are actively used as a proxy for revealing the climate change in the late Quaternary even in tropical area, however, these paleo environmental archives are only recorded in the intervals when the speleothem is growing, and they are biased if speleothem growth rate fluctuates seasonally. It is thereby very important to understand the control of stalagmite growth rate**.** In order to elucidate environmental parameter which affects on speleothem growth rate in tropical area, we conducted meteorological, hydrological and geochemical monitoring during a year in Petruk Cave, Central Java, Indonesia. Two dynamic air CO_2 reduction phenomena are observed; (a) daily or sub-daily time scale decrease with airflow direction change driven by air temperature difference change between the outside and the inside cave and (b) seasonal scale decrease that occurred in dry season which is reported first in the world. It is suggested that the seasonal scale fluctuation of air CO_2 level in cave controls the growth rate of speleothem because of the inverse correlation between the air CO_2 level and the speleothem growth rate. It implies that speleothem archives from tropical caves are paleo climatic records of dry season when air CO_2 decreases and the speleothem growth rate increases. Prior calcite precipitation (PCP) mass fluctuation in the cave might be controlled by the fluctuation of air CO_2 concentration because concentration of calcium ion in drip water correlates with air CO_2 level.

In Chapter IV, a new drip water sampling implement was installed in Petruk Cave and the effect of CO_2 level fluctuation to speleothem growth rate is estimated precisely. Chemical composition and parameters before the speleothem depositing reaction and after that are determined and compared. CO_2 was degased faster than calcite precipitation and $S.I._{cc}$ increased during the reaction on the implement. These results are similar to the previous model suggested by Dreybrodt and Bahman (1985) and Dreybrodt and Sholtz (2011). However, some phenomena which cannot be explained by the existing molecular diffusion model are found. Although degassing mass is proportional to ΔpCO_2 (the difference between CO_2 partial pressure in drip and cave air), precipitation mass is not correlated with that. It is presumed that short time scale fluctuation of air CO_2 around the entrance affects speleothem growth rate.

In Chapter V, we discuss relationships among cave micrometeorology, speleothem growth and surface environment, useful scheme for interpreting speleothem archives and necessary future works. Air temperature and humidity only in shallow part of cave are affected by surface meteorology both in tropic and temperate cave, whereas $pCO_{2\text{-air}}$ both in tropic and temperate cave is affected by surface air temperature change. It was found that $pCO_{2\text{-air}}$ decreased in dry season in tropical cave and that phenomenon cannot be explained through the existing cave ventilation model. It is suggested that speleothem growth rate is the proxy of change of surface air temperature in temperate area and the proxy of aridity (fluctuation of precipitation) in tropical cave if speleothem is sampled where drip rate cave humidity, drip rate or (Ca^{2+}) are stable. It is better that speleothem archives are sampled where air temperature, humidity, drip rate and (Ca^{2+}) do not fluctuate well, because there are few caves where $pCO_{2\text{-air}}$ is stable, for interpretation of speleothem growth rate fluctuation as a paleo environmental proxy.