The occurrence of phreatic overgrowth over speleothems (POS) and their use as Holocene paleo sea-level indicators on Minami Daito Island, West Pacific

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THE OCCURRENCE OF PHREATIC OVERGROWTH OVER SPELEOTHEMS (POS) AND THEIR USE AS HOLOCENE PALEO SEA-LEVEL INDICATORS ON MINAMI DAITO ISLAND, WEST PACIFIC

Abstract

Phreatic overgrowths on speleothems (POS) are rare calcium carbonate deposits on speleothems and cave walls occurring in groundwater pools of some coastal caves. The POS-forming calcium carbonate precipitates on the very top of the water column at the interface with the air. Because of the proximity to the sea, the groundwater level fluctuates according to the tide and thus the POS form within the fluctuation range of the groundwater level. This narrow and well-defined occurrence combined with the precise dateability makes POS an excellent sea-level indicator.

The aim of this research is two folded. One is to characterize the POS found on Minami Daito Island (Northern Philippine Sea/West Pacific) petrographically, geochemically, and mineralogically with a tentative characterization of the geochemical environment in which they form. Second, the POS were used to study Holocene sea-level change on the island.

Thin and thick sections of POS were made and analysed under petrographic and scanning electron microscope (SEM). Thick sections were also etched for mineral fabric observation. SEM energy dispersive X-ray spectroscopy (EDS) analysis was performed for trace element analysis of the POS-forming carbonate and X-ray diffraction (XRD) analysis was made to identify the mineralogy of the POS. Basic chemical characterization of the water in which POS form was also carried out and the saturation index calculated. The calcite slabs were put into the water to observe the modern saturation state of the cave groundwater.

To study the palaeo sea level, the groundwater fluctuation in caves where POS occur was observed and its relation to the POS determined. For the purpose, the groundwater level fluctuation during spring tides was observed in four caves by photomonitoring and the difference between the highest groundwater level and the highest POS level was measured. In order to determine the time at which the POS started to form, the oldest carbonate layers at the highest part of three POS samples were dated by radiocarbon method. The dead carbon proportion (DCP) (the “reservoir effect”) was estimated by analysing the modern POS precipitates and their DCP.

Microscope observations of polished and etched surfaces of thin and thick sections show that dendritic is the prevailing fabric in POS. Alongside, fibrous and isotropic fabrics are also present. XRD analyses demonstrate that the POS are mostly formed of Mg-calcite (4-7% $MgCO_3$) although aragonite was also identified. EDS analysis also revealed substantial content of Mg in the crystals which corroborates the XRD analysis results confirming the presence of Mg-calcite. It further helped to distinguish the mineralogy on microscale; the identified fibrous crystal fabrics do not contain Mg and are thus most probably formed of aragonite. Aragonite most commonly occurs as cement in the pore space of the dendritic crystals. Larger amount s of aragonitic crystals at the edge of POS results in a smooth botryoidal surface. Pool water analyses indicate a Ca/Mg ratio with a slight downward trend from 0.5 on the surface to 0.4 at 2 m depth. The CO_2 partial pressure on the other hand increases from ca 450 ppm to 13 000 ppm within the same depth range. The comparison of salinity of drip water and pool surface

water shows that the surface water is mainly composed of drip water with only about 1% seawater. The calculated saturation index (SI) shows that the water saturated with respect to calcite only on the surface. SEM analysis of the calcite slabs left in the pool water fro ca. 4 months, however, show dissolution at both depths. At 1 m depth the dissolution seems to be more delicate and bringing up the texture of the rock, while on surface the dissolution appears more indiscriminate.

The observation of groundwater level fluctuation during spring tides in four caves shows that modern highest groundwater level is ca. 60 cm below the highest POS level. Radiocarbon analysis of modern precipitates show DCP values between 1.6 and 5.7 % indicating that the oldest and highest parts of POS were deposited in mid-Holocene, between 5.1 and 4.6 ka ago respectively.

Chemical and mineralogical characterization indicates that the POS were formed in water with a relatively high Mg/Ca ratio, which is consistent with the Mg/Ca ratio of the modern pool water. The source of Mg could be either marine water with which the pool water partly mixes, or vadose water percolating through dolomite rock, or both. The calculated seawater proportion in the modern cave pool surface water strongly suggests that the source of Mg is drip water. The occurrence of various mineral species within a POS suggests a changing geochemical environment in the cave, which might possibly related to climate variations (precipitation) between the mid-Holocene in the present. The SI values support the theoretical background of POS formation at the very top of the water column, which is also corroborated by CO_2 partial pressure values and observed floating calcite rafts. The dissolution of the calcite slabs at the top as well as at -1 m level, however, suggests seasonal variability of SI.

The 60 cm difference between the highest POS and modern highest groundwater level can be partly attributed to the uplift of the island in the time span of 4 to 5 ka, while the remaining 30 cm suggest a slight sea level drawdown since mid-Holocene, which is also very small compared to the mid-Holocene sea level highstands observed elsewhere. In addition, it cannot be completely excluded that the observed 30 cm drawdown has resulted from a decrease in rainfall or other phenomena affecting the groundwater level. Either way, the inferred sea-level history indicates a relative stability of the sea level in this region and the relative sea level curve tightly resembles the eustatic curve. The absence of an unambiguous mid-Holocene sea-level highstand could be due to the mantle and crust properties of the Philippine Sea Plate and the location of Minami Daito (at ca. 27° latitude) near the edge of the typical occurrence of the mid-Holocene sea-level highstand, i.e. 30° latitude). The approximate time at which sea level reached its peak on Minami Daito is close to the assumed end of Antarctic ice sheet melting, i.e. ca. 4 ka ago.

Minami Daito is one of the three islands located in the middle of the Northern Philippine Sea area and therefore sea-level history data obtained from the island are very valuable for understanding the local sea level variability, and even more for the understanding of the global sea-level response to the intricate Earth and climate ever-changing dynamics.