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Seasonal variation in water chemistry and depositional processes in a tufa-bearing stream in SW-Japan, based on 5 years of monthly observations

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Abstract

Annually laminated freshwater carbonate (tufa) is a potential source of high-resolution terrestrial paleoclimate data. In order to understand the processes and characteristics of climate information recorded in tufa, the chemical components of carbonate-rich water, its flow rate and soil P_{CO_2} were recorded monthly during a 5-year period (December 1997 to December 2002) at Shimokuraida (Niimi City, Okayama Prefecture), SW-Japan. Water issues from a limestone cave there flows along a 450-m long stream and deposits tufa that commonly exhibits distinct annual laminations.

Among observed properties, the CO_2 partial pressures in the soil and the spring water show the clearest seasonal patterns, which are similarly high in summer–autumn and low in winter–spring. The spring-water P_{CO_2} partly reflects soil P_{CO_2}, but is controlled by another temperature-dependent process, natural ventilation between the subsurface and the atmosphere. The concentration of dissolved $CaCO_3$ does not mirror the seasonal pattern of spring-water P_{CO_2}, but is largely influenced by rainfall dilution. The development of annual laminations results from seasonal changes in the depositional rate of $CaCO_3$, which was faster from summer to autumn and slower from winter to spring. This seasonal pattern is initially controlled by relatively regular changes in water temperature and flow rate, both of which correlated positively with the calcite precipitation rate. High calcite precipitation in summer–autumn formed a densely calcified texture, whereas a precipitation low rate winter–spring formed a porous texture. Changes in the concentrations of minor dissolved components (Mg^{2+}, Na^+, K^+, Cl^-, NO_3^-, SO_4^{2-} and SiO_2) exhibited no seasonal pattern. Because the amplitude of the Mg/Ca change is very high at Shimokuraida, the Mg/Ca ratio of tufa (calcite) does not reflect paleotemperatures. While, Mg/Ca ratio of water does not correspond to rainfall intensity, too.

Keywords: Tufa; Freshwater carbonate; Water chemistry; Seasonal variation; SW-Japan

1. Introduction

Tufa is a freshwater carbonate that is deposited in open-air conditions in limestone areas (Ford and Pedley, 1996) and is an important source of paleoclimatic records (Andrews et al., 2000; Smith et al.,

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2004). Tufa is suitable for high-resolution climatic analysis due to its relatively fast depositional rate and annual laminations. Trace element and stable isotope analyses have shown that tufa provides climatic records (e.g., temperature and rainfall) in week-to-month resolution (Matsuoka et al., 2001; Ihlenfeld et al., 2003; Kano et al., 2004). Tufas are ubiquitous in temperate-tropical climatic areas and, together with speleothems, can be used to predict climate change in densely populated areas.

Since climatic analysis of tufa has been utilized only in recent years, it is still uncertain how applicable the previously proposed analytical procedures are to global climate studies, because tufa-depositing systems are very local. The texture and gross morphologies of tufa deposits vary due to depositional and climatic settings (Pedley, 1990; Kano and Fujii, 2000; Carthew et al., 2003). Reliable climatic analysis should be based upon the monitoring of seasonal change and/or the stability of water chemistry, which influence the texture and chemical composition of tufa.

The most important textural character of tufa is its annual laminations. We have demonstrated (Kano et al., 2003) for a tufa at Shirokawa (Ehime Prefecture, southwest Japan) that dense laminae form in summer to autumn and porous laminae form in winter to spring. We also suggested that the lamination pattern reflects seasonal change in the calculated precipitation rate of calcite (Kano et al., 2003), which correlates positively with water temperature, alkalinity and Ca^{2+} content (Plummer et al., 1978). Values for these three water properties at Shirokawa were high from summer to autumn and low from winter to spring.

The trace element concentrations in water determine their concentrations in the tufa. For instance, the Mg/Ca ratio of the tufa, as well as its δ^{18}O value, are potential paleothermometers, because of the temperature-dependency of the partitioning coefficient between water and calcite. These potential paleothermometers are based on the assumption that the chemical composition of water has remained stable (within a small range) for an extended time period. The tufa-depositing water normally originates from a limestone aquifer, and its chemical composition expectably varies with the local weather and hydrological conditions such as air temperature, humidity–aridity, water sources and the residence time of the water.

Long-term monitoring of water properties is the best way to study the deposition of tufa. This study describes the results of monthly observations over a 5-year period (from December 1997 to December 2002), at a tufa-bearing stream at Shimokuraida, Niimi City, southwest Japan (Fig. 1). We also discuss some important stream and underground processes using a large data set.

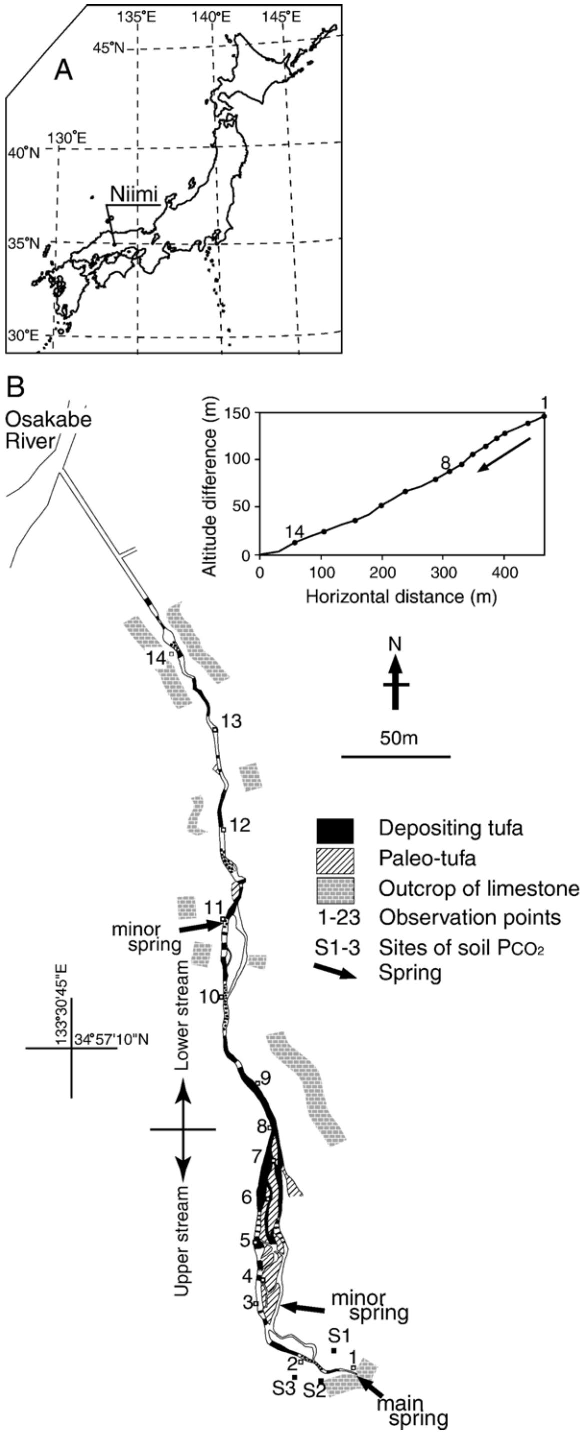

Fig. 1. (A) Location of study area, (B) map and course of the tufa-bearing stream at Shimokuraida in Niimi City (Okayama Prefecture, Japan).