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Mineralogical, crystallographic, and isotopic constraints on the precipitation of aragonite and calcite at Shiqiang and other hot springs in Yunnan Province, China

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ABSTRACT

Two active spring vent pools at Shiqiang (Yunnan Province, China) are characterized by a complex array of precipitates that coat the wall around the pool and the narrow ledges that surround the vent pool. These precipitates include arrays of aragonite crystals, calcite cone-dendrites, red spar calcite, unattached dodecahedral and rhombohedral calcite crystals, and late stage calcite that commonly coats and disguises the earlier formed precipitates. Some of the microbial mats that grow on the ledges around the pools have been partly mineralized by microspheres that are formed of Si and minor amounts of Fe. The calcite and aragonite that are interspersed with each other at all scales are both primary precipitates. Some laminae, for example, change laterally from aragonite to calcite over distances of only a few millimetres. The precipitates at Shiqiang are similar to precipitates found in and around the vent pools of other springs found in Yunnan Province, including those at Gongxiaoshe, Zhuyuan, Eryuan, and Jifei. In all cases, the δD_{water} and $\delta^{18}O_{water}$ indicate that the spring water is of meteoric origin. These are thermogene springs with the carrier CO_2 being derived largely from the mantle and reaction of the waters with bedrock. Variations in the $\delta^{13}C_{travertine}$ values indicate that the waters in these springs were mixed, to varying degrees, with cold groundwater and its soil-derived CO_2. Calcite and aragonite precipitation took place once the spring waters had become supersaturated with respect to $CaCO_3$, probably as a result of rapid CO_2 degassing. These precipitates, which were not in isotopic equilibrium with the spring water, are characterized by their unusual crystal morphologies. The precipitation of calcite and aragonite, seemingly together, can probably be attributed to microscale variations in the saturation levels that are, in turn, attributable to microscale variations in the rate of CO_2 degassing.

1. Introduction

Thermal springs, found throughout the world (Waring, 1965), are natural laboratories characterized by waters with variable temperatures, pH, and water chemistry. Hot springs with water discharged at temperatures above 37.5 °C (Pentecost et al., 2003) to 40 °C (Renaut and Jones, 2000) are characterized by bewildering diversity in their mineral assemblages (e.g., calcite, aragonite, opal-A), crystal morphologies (e.g., calcite dendrites), and/or microbiology. As more and more of these hot springs are being examined it is becoming increasingly apparent that they are complex systems controlled by a myriad of intrinsic and extrinsic parameters that may act independently or in unison. The presence of calcite and aragonite, which are common components of many hot spring deposits (Kitano, 1955; Folk, 1974; Renaut and Jones, 1997; Pentecost, 2005), usually engenders the question of what controlled the precipitation of these two polymorphs. As discussed by De Choudens-Sánchez and González (2009, pp. 363–364) the precipitation of calcite as opposed to aragonite, irrespective of where it forms, has been attributed to many different factors such as water temperature, Mg/Ca ratio, and saturation levels. This is certainly true for calcite and aragonite that are commonly found in the deposits around hot springs (e.g., Renaut and Jones, 1997; Peng and Jones, 2013; Jones and Peng, 2014a).

The precipitates in and close to many hot spring vent pools in Yunnan Province, China (Fig. 1), are formed of calcite and/or aragonite and various accessory minerals that commonly develop in association with the microbial mats that thrive in these settings (e.g., Jones and Peng, 2012a, 2014a, 2014b; Peng and Jones, 2013). The distribution and crystal morphology of the calcite and aragonite found in these deposits are highly variable at all scales. This is clearly apparent at Shiqiang (also known as Stone Wall) where there are two active but unnamed hot spring pools that are about 3 m apart (Figs. 1, 2). Although both springs have walls built around them (Fig. 2), the vent pools and

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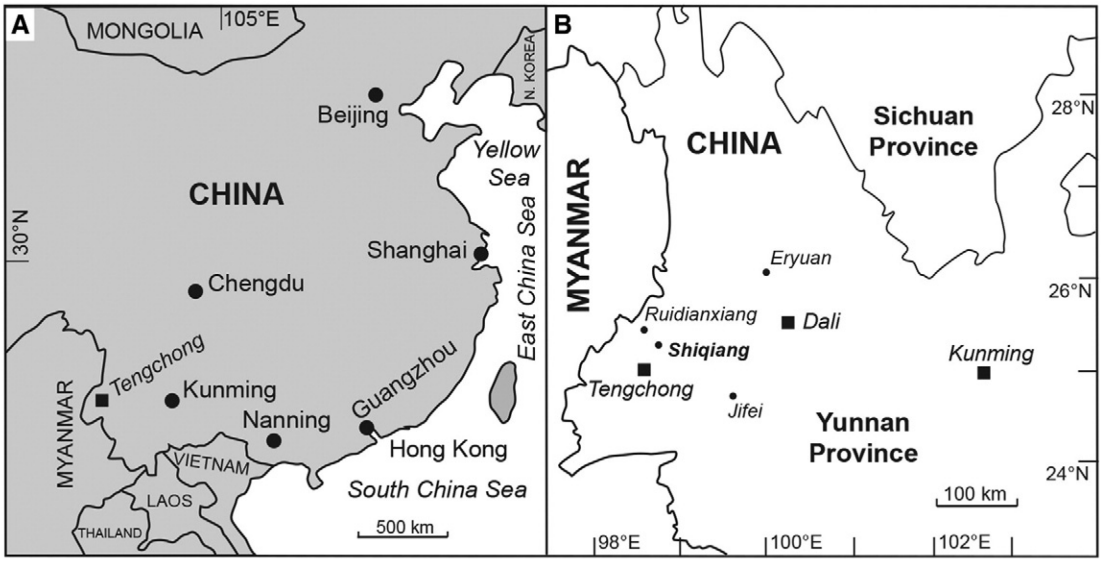

Fig. 1. Location of study area. (A) Map of China showing location of Tengchong, which is the nearest city to Shiqiang. (B) Location of Shiqiang relative to other springs at Tengchong, Ruidianxiang, Eryuan, and Jifei.

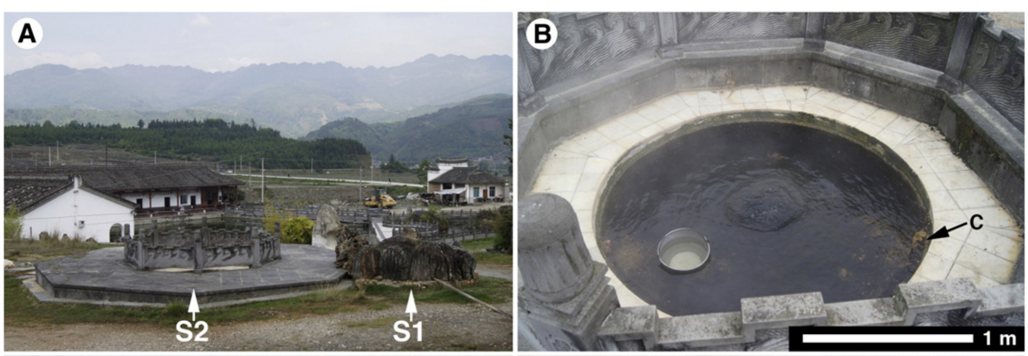

Fig. 2. Views of active springs at Shiqiang. (A) General view to north showing location of springs S1 and S2. (B) Spring S2, surrounded by white tiled ledge and a concrete wall. (C) Edge of S2 pool showing submerged precipitates around wall. (D) General view of vent pool at S1. (E) View of margin around vent pool at S1 showing ledges and green microbial mats. (F) Ledge around vent pool of S1 showing precipitates on ledge that is above water level.