Sedimentary Geology 342 (2016) 218–236

Contents lists available at ScienceDirect

Sedimentary Geology

journal homepage: www.elsevier.com/locate/sedgeo

Sedimentology, petrography and early diagenesis of a travertine–colluvium succession from Chusang (southern Tibet)

Zhijun Wang [a], Michael C. Meyer [a,*], Dirk L. Hoffmann [b]

[a] Institute of Geology, University of Innsbruck, Innrain 52, 6020 Innsbruck, Austria
[b] Department of Human Evolution, Max Planck Institute for Evolutionary Anthropology, D-04103 Leipzig, Germany

ARTICLE INFO

Article history:
Received 15 March 2016
Received in revised form 30 June 2016
Accepted 3 July 2016
Available online 12 July 2016

Editor: Dr. B. Jones

Keywords:
Tibetan Plateau
Hydrothermal spring carbonate
Travertine
Colluvium
Early diagenesis
Monsoon

ABSTRACT

The Chusang travertine is situated in southern Tibet at an altitude of ~4200 m asl. in a cold-arid, periglacial environment and is characterized by interbedding of hydrothermal carbonate with colluvium. Here we present sedimentological and petrographical data to elucidate the depositional environment and sedimentary processes responsible for hydrothermal carbonate precipitation and early diagenetic alteration as well as clastic sediment accumulation and provide initial ^{230}Th/U ages to constrain the time-depth of this travertine–colluvium succession. Three main travertine lithofacies have been identified: 1) a dense laminated lithofacies, 2) a porous layered lithofacies and 3) an intraclastic lithofacies that results from erosion of pre-existing hot spring carbonate. The colluvium is composed of cohesive debris flow layers that derived from mass-wasting events from the adjacent hillslopes. Micro-fabric analyses suggest that dense laminated travertine forms via rapid calcite precipitation from hot spring water seasonally subjected to severe winter cooling, while porous layered travertine results from seasonal dilution of hot spring water with rain water during the summer monsoon months, which in turn stimulates biological productivity and gives rise to a porous summer layer. Early diagenesis in the form of recrystallization and extensive formation of pore cements is common in the Chusang travertine, but never eradicates the original crystal fabrics completely.

The sedimentary architecture of the deposit is conditioned by (i) the gently dipping (~10°) pre-existing terrain on which hot spring water is discharged from multiple travertine mounds causing laterally extensive travertine sheets to precipitate, and (ii) the adjacent much steeper (up to 30°) periglacial hillslopes that are the source area of repeated debris flows that accumulate on the travertine surface. The resulting travertine–colluvium succession has a total thickness of ~24 m and ^{230}Th/U dating suggests that the base of this succession has a minimum age of ~486 ka, while the upper part (top-most ~8 m) of the succession started accumulating in the earliest Holocene. We hypothesize that hot spring activity (and thus travertine precipitation) and the occurrence of debris flow events has a climatic nexus, i.e. are both triggered by phases of enhanced Indian summer monsoon.

1. Introduction

Travertines are continental spring carbonates that precipitate from hydrothermal water (generally >30 °C in temperature) and that are typically bound to crustal-scale faults in extensional tectonic regimes (Özkul et al., 2002; Zentmyer et al., 2008; Capezzuoli et al., 2014; Della Porta, 2015; Croci et al., 2016). High rates of carbonate precipitation are common in travertines (frequently ≥1 cm/year; Pentecost, 2005) with two major consequences: (i) rapid crystal growth that results in high primary porosity, and (ii) high temporal resolution of proxy signals stored in these deposits. The latter effect is often expressed as lamination that resolves climate and temperature variability on a seasonal (Chafetz and Folk, 1984; Liu et al., 2010), and sometimes monthly or even diurnal scale (Chafetz and Folk, 1984; Takashima and Kano, 2008). Furthermore, spring carbonates such as travertines are – at least in principle – amenable to uranium-series disequilibrium dating (e.g. ^{230}Th/U dating; Mallick and Frank, 2002; Garnett et al., 2004; Stone et al., 2010) as well as luminescence dating (Rich et al., 2003; Mahan et al., 2007; Vazquez-Urbez et al., 2011), and are hence valuable archives of paleoclimatic and paleoenvironmental change (Frank et al., 2000; Minissale et al., 2002; Faccenna et al., 2008; Liu et al., 2010; Toker et al., 2015). In several reported instances travertines as well as other types of continental spring carbonates are also stratigraphically and/or spatially associated with archeological remains, especially in arid and semi-arid areas (the Tibetan highlands included) and can thus act as valuable archeological repositories too (Grün et al., 1988; Hill, 2001; Zhang and Li, 2002; Smith et al., 2004, 2007; Ashley et al., 2010).

Exploiting the paleoenvironmental and geoarcheological information stored in travertines is, however, impeded by the fact that these deposits are prone to early diagenesis, because of their high initial porosity

* Corresponding author.
E-mail address: michael.meyer@uibk.ac.at (M.C. Meyer).

http://dx.doi.org/10.1016/j.sedgeo.2016.07.002
0037-0738/

and permeability (Pentecost, 2005; Jones and Renaut, 2010; Capezzuoli et al., 2014). Diagenesis can alter the geochemical composition and thus paleoclimatic proxy signals recorded in spring carbonate deposits (Andrews, 2006), and also cause problems for ^{230}Th/U dating (e.g. open-system behavior with respect to uranium and/or thorium; Garnett et al., 2004; Stone et al., 2010). Moreover, detrital material (e.g. clay minerals) might afflict the quality of ^{230}Th/U dates of these deposits. Hence, a detailed study of the macroscopic and microscopic crystal fabrics and reconstruction of the depositional environments is necessary to gain insights into the sedimentary and diagenetic history of travertines (Chafetz and Folk, 1984; Jones and Renaut, 2008; Rainey and Jones, 2009) and to assess their fidelity as a paleoenvironmental archive.

On the Tibetan Plateau, hydrothermal springs and travertine deposits are common and preferentially occur along north–south trending active graben systems (Tong et al., 2000). Yet, in a Tibetan context, these hydrothermal spring carbonates are severely under-researched. Little is known about the nature of paleoclimatic information stored in these carbonates and the paleoenvironmental significance of past periods of travertine formation. The few Tibetan travertine sites that have been described so far include the Targjia and the Zabuye travertine (both central Tibet; Zhao et al., 2006; Zhao et al., 2010), the Nyalam travertine (southern Tibet; Zentmyer et al., 2008) and the Rongma travertine (northern Tibet; Gao et al., 2013). One particularly interesting travertine site is situated ca. 80 km northwest of Lhasa (Chusang; Fig. 1), where nineteen human hand- and footprints were discovered on the surface of the Chusang travertine (Zhang and Li, 2002), and are thought to be of Late Pleistocene age (Zhang and Li, 2002; Zhang et al., 2003), rendering Chusang an archeological key site for the Tibetan Plateau. Furthermore, the travertine deposit at Chusang is interbedded with colluvium and alluvium resulting in a ~24 m thick succession of hydrothermal carbonate and detrital terrigenous strata. Only very few examples of such mixed travertine-terrigenous successions have been described so far (e.g. Schulte et al., 2008; Zentmyer et al., 2008; Özkul et al., 2014; Claes et al., 2015; Croci et al., 2016), but these studies already highlight the variety of lithofacies types and different depositional architectures encountered in these deposits.

Alluvial fans and colluvial deposits are common on the Tibetan Plateau, owing to the sparse vegetation cover and periglacial processes operating on the hillslopes. Nevertheless, these unconsolidated sediments are also highly erodible; hence most of these terrigenous deposits reflect the latest Pleistocene and Holocene sedimentary dynamics on the plateau only (Wang and French, 1995; Kaiser et al., 2007, 2009). In the case of Chusang, however, the travertine layers are shielding the interbedded colluvial strata from erosion, and it is thus likely that in the stratigraphically lower part of the succession much older colluvium is preserved as compared to the adjacent hillslopes, allowing sediment based climate records to be extended back in time.

In this study, we conducted sedimentological and petrographic analyses on the travertine–colluvium succession of Chusang in order to reconstruct its stratigraphic architecture and depositional environment, to elucidate the processes responsible for travertine precipitation and to investigate the degree of diagenetic alteration. This work thus (i) lays the foundation for a ^{230}Th/U dating study, designed to provide an accurate chronological framework for the Chusang travertine succession and the human imprints encased in this carbonate (ii) is one of the first studies that focuses on the interplay between thermogene travertine and alluvial/colluvial deposition in a cold-arid periglacial environment and (iii) provides a conceptual model for the relationship between an enhanced summer monsoon and the sedimentary evolution of the Chusang succession.

2. Geomorphological setting and basic sedimentary architecture

The Chusang travertine is located near the village of Chusang (variously referred to as Quesang or Qiusang in the literature) about 80 km northwest of the city of Lhasa (Fig. 1). Today, the mean annual air temperature (MAAT) in the study area is ~4 °C (derived by adjusting the MAAT of Lhasa to an altitude of 4200 m asl. using the average atmospheric lapse rate of 0.65 °C/100 m) and the mean annual precipitation (MAP) is ~430 mm (data from the Public Weather Service Center of China). This part of the Tibetan Plateau is under the influence of the Indian and South Asian summer monsoon, delivering ca. 88% of the MAP between June and September (Public Weather Service Center of China).

The travertine deposit covers ~0.6 km^2 of a gently inclined (~5–12°) NW-facing slope between ~4070 m and 4280 m above sea level (asl.). Two hot springs with a discharge of ~0.1–0.3 L/s are present at the travertine site (Fig. 1). The main spring is situated at 4270 m asl. and is used in a public bath house (Fig. 1). Steeper slopes are surrounding the travertine and extend up to 4905 m asl. Periglacial slope and mass-wasting processes (frost creep, solifluction) and scarps formed by soil creep and active layer-detachment slides are abundant in the steeper upslope areas above ~4280 m (Fig. 1C, D). A ~560 m-long head scarp is present at the eastern end of the Chusang travertine at an elevation of 4300 m and ~185 m upslope of the main hot spring (Fig. 1C, D). Approximately 1.5 m of displacement and several fresh sinkholes can be observed along this scarp suggesting ongoing subrosion. No additional or superordinate landslides were observed in remote imagery or during the field campaigns at Chusang or in any of the adjacent catchments.

Two ephemeral streams incise into the Chusang travertine along its southern and northern margin, respectively (Fig. 1), exposing individual travertine sheets that alternate with layers of colluvial and occasionally alluvial sediment (Figs. 2, 3). Logging along the southern and the northern gully as well as inspection of outcrops along the street reveals at least seven such clastic layers (Fig. 4). Individual travertine beds attain a thickness of 0.3 to 7 m, while layers of clastic sediments vary from 0.5 m to 4 m in thickness. The entire thickness of this travertine–colluvium succession is ~24 m. In the upper part of the Chusang travertine (between ~250 m and ~330 m downslope of the modern main spring; Fig. 1C, D) at least five paleo-spring orifices, some up to 3 m in diameter and 2 m in height, are located. These orifices represent remnants of former travertine mounds and cones (Figs. 2B, 3A; Pentecost, 2005) and occur in the same stratigraphic horizon. Travertine sheets precipitated from water that discharged from these orifices, causing coalescing of the mounds and cones into an interconnected complex (Figs. 1D, 2A). Additional travertine mounds are present at Chusang but are less well-preserved. In south-eastern direction (i.e. upslope towards the human imprints and the modern main hot spring) further layers of travertine and colluvium are overlying this complex with the main modern hot spring discharging on top of this succession (Fig. 2A). Other travertine features such as larger slope terraces, travertine pools or dams are absent. Smaller terraces, mini-rimstone and shallow ponds exist but most of them suffered from surface erosion or are partly covered by clastic sediment.

3. Geological setting

The area of Chusang travertine is composed of a sequence of shallow-marine and clastic sedimentary rocks (limestone, sandstone and siltstone), as well as volcanic rocks (tuffaceous rocks, dacite, andesite and lava breccia). This sequence is known as Chaqupu Formation and extends from the Late Paleozoic into the Mesozoic (Zhang, 1997; Xie et al., 2010). Thin-section analysis of a sample obtained from the bedrock that underlies the Chusang travertine at its eastern margin yielded an oolite limestone, which according to Xie et al. (2010) is Triassic in age. The volcanic rocks occur stratigraphically and tectonically below these carbonates and thus likely constitute the deeper parts of the Chusang aquifer (Xie et al., 2010). Tectonically speaking, the study area is part of the Lhasa terrane and situated 27 km east of the Yadong-Gulu graben system (Armijo et al., 1986; Yin and Harrison, 2000), one of six approximately north–south striking graben systems