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Radiocarbon dating of aquatic gastropod shells and its significance in reconstructing Quaternary environmental changes in the Alashan Plateau of northwestern China

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ABSTRACT

Using landform evolution and lake sediment records to reconstruct Quaternary environmental changes requires reliable chronology. However, there is an ongoing debate regarding the fossil shells of aquatic gastropods in carbonate rock area to be used for radiocarbon dating. The focus of this debate is whether living gastropods incorporate the dead carbon, which would affect the accuracy of the dating results. Living aquatic gastropods were selected from habitats on carbonate terrain in arid region. In this study, 64 shell samples from living gastropods, including *Cipangopaludina chinensis*, *Gyraulus convexiusculus*, and *Radix auricularia*, collected from the Alashan Plateau of northwestern China, were dated by accelerator mass spectrometry (AMS) ^{14}C dating. The results revealed that only five samples (~8%) from the same site contained no dead carbon. The other 59 samples (~92%) contained dead carbon in various amounts: ~59% samples contained 0–10% dead carbon, and ~33% samples contained more than 10% dead carbon. Of the samples, 56 were *Radix auricularia* and their ^{14}C ages varied from present to 3253 cal yr BP. Two of the samples were *Gyraulus convexiusculus* samples dated at 379 and 290 cal yr BP which are highly consistent with ^{14}C ages of *Radix auricularia* samples from the same site. The other six *Cipangopaludina chinensis* samples were dated at 407–863 cal yr BP. Thus, most of living aquatic gastropods from habitats on carbonate terrain contained dead carbon. The amount of dead carbon in the gastropod shells was nonselective among the three species. Radiocarbon dating of aquatic gastropod shells may not be useful for studying processes that occurred over multi-millennial timescales at different localities in areas of carbonate rock. It is difficult to establish high-resolution chronologies using ^{14}C ages of gastropod shells in arid regions with carbonate rocks unless the limestone effect has been corrected.

1. Introduction

Landform evolution and lake sediment records can be used as reliable indicators of Quaternary environmental change (Zhang et al., 2002; Xiao et al., 2004; Yancheva et al., 2007; Boxleitner et al., 2017; Rossetti et al., 2017), and regional environmental changes usually respond sensitively to global environmental change (Yang et al., 2011; Li et al., 2016; Goldsmith et al., 2017). A common approach to reconstructing lake surface areas and past landform evolution of lake basins is to investigate constructional, sandy lake shoreline features (Zhang et al., 2004; Long et al., 2012; Li et al., 2016). Using such landform evolution and lake sediment records to reconstruct past environmental changes requires reliable chronology (Zhang et al., 2006; Wang et al., 2012; Zhang et al., 2016; Wang et al., 2017). Therefore, accurate dating results are important in reconstructing paleoenvironments and understanding the mechanisms of past global changes (Wang et al., 2013).

Radiocarbon (^{14}C) dating is one of the most frequently used dating techniques to establish chronologies for landform evolution and lake sediments spanning the past ~50,000 years (Geyh et al., 1998; Liu et al., 2016). However, few materials suitable for ^{14}C dating are present in arid regions, which is a problem in studies of geomorphology and geochronology. The reservoir effect or limestone effect makes it difficult to establish reliable chronologies in arid regions (Zhang et al., 2008; Zhang et al., 2016). Hence, the selection of suitable dating materials and use of reliable dating results to reconstruct sedimentary environment and paleoenvironmental change have been a focus of recent studies. Accurate determination of the contribution of the reservoir effect or limestone effect is essential to establishing an accurate and precise chronology using radiocarbon dating.

Fossil shells of small gastropods, largely composed of aragonite ($CaCO_3$), are commonly preserved in layers of lake sediments in arid regions. However, there is ongoing debate regarding the suitability of

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shells for radiocarbon dating. The focus of this debate is whether living gastropods incorporate dead carbon (limestone effect), which would affect the accuracy of dating. Some previous studies have suggested that gastropods consistently incorporate dead carbon when it is available (Goodfriend and Stipp, 1983; Zhou et al., 1999; Quarta et al., 2007; Romaniello et al., 2008). Whereas other studies have suggested that small shells generally yield reliable ^{14}C ages for Quaternary wetland, loess, and lacustrine deposits (Brennan and Quade, 1997; Pigati et al., 2004; Placzek et al., 2006; Pigati et al., 2013; Pigati et al., 2015; Macario et al., 2016). Hence, radiocarbon dating of fossil shells provides conflicting results in different regions.

The Alashan Plateau, located in the arid region of northwestern China, is part of the marginal area of the Asian summer monsoon (Wang et al., 2005). In this area, changes in the water level of terminal lakes were sensitive to climate change during the late Quaternary. Gastropod shells, including *Radix auricularia*, *Gyraulus convexiusculus*, and *Cipangopaludina chinensis*, from the lake sediments and shorelines in this area have been selected for radiocarbon dating to reconstruct lake evolution and environmental change during the late Quaternary (Zhang et al., 2004; Long et al., 2010; Wang et al., 2011; Li et al., 2015). Aquatic mollusks eat dissolved inorganic carbon (DIC) derived from organisms (McConnaughey and Gillikin, 2008). In some environments, DIC might show a reservoir age due to dissolution of catchment limestone and/or mineralization of old organic matter that was fossilized into the lake. Therefore, it remains uncertain whether these gastropods incorporated dead carbon, which could lead to difficulties in establishing reliable chronologies.

In this study we examined ^{14}C dating results from 64 shell samples of living gastropods collected from the Alashan Plateau, to determine whether the living gastropods incorporated dead carbon from limestone or other carbonate rocks. We then evaluated whether the shells in this region are suitable for ^{14}C dating and if the current paleoenvironmental and climatic reconstructions, for which gastropod shells were used, need to be reconsidered.

2. Study area

The Alashan Plateau, which forms part of the southern Mongolian Plateau, has an area of approximately 300,000 km^2 (Li et al., 2015). The Mazong Mountains are located to its west and the Helan Mountains are to its east (Fig. 1). The plateau has an altitude of 1500–2000 m above sea level (a.s.l.), includes several mountains with elevations greater than 2000 m, and is lowest, with an elevation of 820 m, near Ejina Banner (Li et al., 2013). Arid denudations on the plateau rise to about 100–200 m, which divide the plateau into several inland basins (Wang et al., 2011). The landscape of the plateau is desert and desert steppe, with moving dunes (Li et al., 2018). The plateau includes the Badain Jaran, Tengger, and Ulan Buh deserts. Of these, the Badain Jaran Desert and the Tengger Desert are located along the two sides of the Yabulai Mountains, which trend northeast to southwest (Wang et al., 2011; Chen et al., 2018).

The sedimentary strata have been deposited continuously since the Paleozoic. Carbonate rocks including limestone and dolomite, with an area of 10,000 km^2, are widely distributed (Fig. 2). In the eastern and southern parts of the plateau, limestone was primarily deposited during the Ordovician, Carboniferous, and Permian. The Ordovician and Permian limestones occur in the central and western parts of the plateau (Fig. 2). Inland rivers such as Shiyang and Heihe Rivers originate in the Qilian Mountains to the south and enter the central and western parts of the Alashan Plateau (Figs. 1 and 2). Therefore, groundwater and surface water in this area contains high concentrations large amounts of HCO^{-}_{3} (Gates et al., 2008; Fan et al., 2009).

The area is located outside of the direct influence of the Asian summer monsoon and the Westerlies, and the present-day climate is extremely dry and continental (Herzschuh et al., 2004). The annual precipitation, which decreases from southeast to northwest, is 50–150 mm, and the mean annual evaporation rate from water surfaces is ~1000 mm y^{-1} (Yang et al., 2011; Li et al., 2016). The annual mean temperature is from 6.8 to 8.8 °C, and the January and July means are from −15.7 to −9.0 °C and from 22.6 to 26.4 °C, respectively (Chen, 2010).

3. Material and methods

3.1. Samples collected

In this study, four habitats, lake, river, reservoir, and pit, were selected (Fig. 3). Among these sites (Table 1), two lakes supplied with groundwater (Sites 1 and 2) were selected, four lakes supplied with runoff (Sites 5, 8, 14, and 15) were selected, six small pits formed by groundwater and supplied with runoff were selected (Sites 3, 4, 6, 7, 11, and 12), one river was selected (Site 10), and two reservoirs were selected (Sites 13 and 16). Moreover, a small pit formed by precipitation without groundwater and runoff supplied (Site 9) was selected to compare those habitats with groundwater and/or runoff supplied. Only living gastropods were collected to verify if the ^{14}C activity of their shells was in equilibrium with the atmosphere. A total of 64 samples were collected from 16 sites across the Alashan Plateau in 2014 and 2015 (Fig. 2 and Table 1).

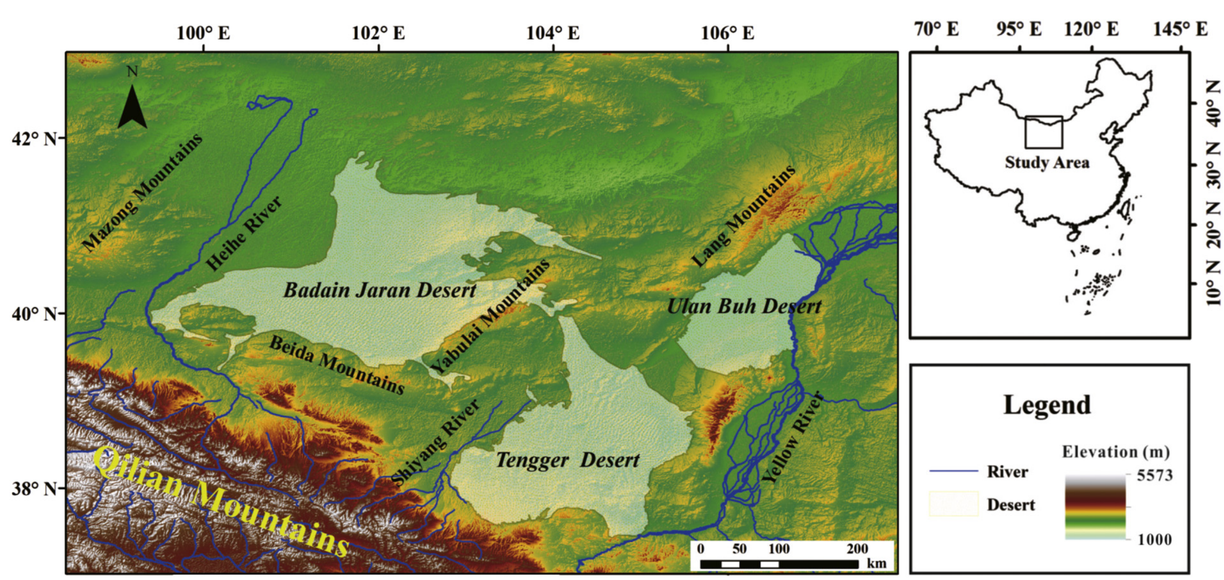

Fig. 1. Location of the study area.