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Short communication

First radiocarbon dating of a Holocene eruption of the Datong volcanic field, eastern China

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ABSTRACT

The accurate dating of prehistoric eruptions is essential for reconstructing volcanic sequences and for preparing volcanic-hazard assessments. The chronology of the eruptions of the Datong volcanic field (DVF) in eastern China has been debated for several decades, especially the start and end of volcanism. Loess sediments incorporated in explosive volcanic products have been described from the Dongpingshan scoria cone in the DVF. We conducted radiocarbon dating of the loess sediments, which produced an age of ~7300 cal yr BP for the Dongpingshan volcanic eruption. This result confirms the eruption of the DVF during the Holocene, and it provides important evidence for assessing volcanic hazards in this densely populated region. The Holocene age of the eruption indicates that DVF is dormant, contrary to previous studies which concluded that the DVF is extinct and that its volcanic eruptions ended at ~100 ka. In addition, this study documents a new method of dating Late Pleistocene to Holocene volcanic eruptions in and around the DVF, where loess sediments are widespread and may be preserved within volcanic products.

1. Introduction

The Quaternary Datong volcanic field (DVF), located in the eastern part of Datong Basin (Fig. 1), is the most important monogenetic volcanic region in eastern China. There are at least 13 volcanic cones in the western part of the DVF, composed predominantly of alkali basalt produced by central-vent eruptions, while the eastern part of the DVF is dominated by lava flows composed mainly of tholeiites produced by fissure eruptions (Basu et al., 1991; Deng et al., 1987; Li, 1988; Li and Xu, 1995; Xu et al., 2005; Yamamoto et al., 2007; Zhang, 1986). Volcanism in the western part of the DVF dates from the Late Pleistocene, at ~0.4 Ma, while in the eastern part it dates from the Early Pleistocene, at ~0.76 Ma (Chen et al., 1992; Cheng et al., 2006; Kaneoka et al., 1983). However, the timing of the ending of volcanism in the region has been debated for several decades (Chen et al., 1992; Li and Sun, 1984; Pei, 1981; Wei et al., 2003; Yin, 1976; Zhao et al., 2015; Zhao et al., 2012; Zhou et al., 1982; Zhu et al., 1990).

K-Ar and Optically-Stimulated Luminescence (OSL) dating are the most common methods for determining the timing of volcanic activity in the DVF (Chen et al., 1992; Zhao et al., 2015). However, excess Ar in K-Ar dating and the relatively low precision of OSL dating may produce results that are too imprecise to date the young volcanic eruptions in the region (Chen et al., 1992; Zhao et al., 2015). However, loess sediments are widespread in Datong Basin (Zhang, 1986), and, if the organic material within loess incorporated in volcanic products can be dated by radiocarbon analysis, it then could provide a valuable means of dating the timing of recent volcanic eruptions in the DVF.

In the Datong Basin, the interactions between volcanism within the DVF, lake level changes, and human activity have been studied (Hu et al., 2017). Visible tephras sourced from DVF explosive eruptions have been observed at the archaeological site of Xujiayao (XJYS), and in paleo-lacustrine sediments nearby (Fig. 1A) (Hu et al., 2017; Zhang et al., 1997). Loess sediments buried by volcanic products have been found at a Neolithic site near Haotianshan volcano (HTS) (Fig. 1A) (Zhang et al., 1997). Therefore, characterizing geochronological sequences of volcanic products from the DVF is important for understanding the impacts of the volcanism on the local environment and the human responses.

We have discovered loess sediments incorporated in the explosive eruptive products from the DVF. Radiocarbon dating the loess indicates that the DVF is a dormant volcanic field, and it also demonstrates the effectiveness of this new method for constraining the ages of volcanic eruptions in and around the DVF.

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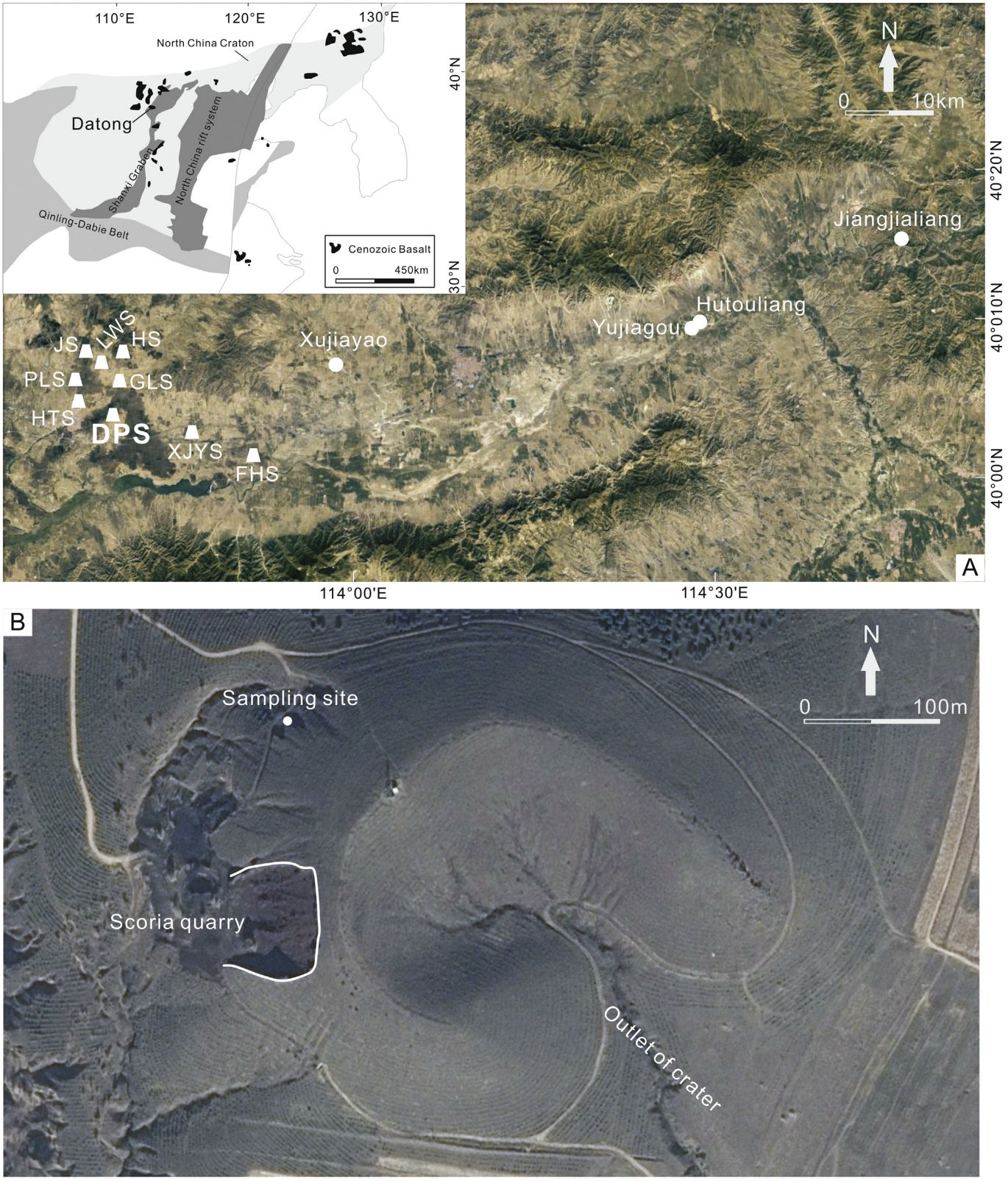

Fig. 1. A: Distribution of Quaternary volcanoes (white trapezoids) in the Datong volcanic field (DVF) and archaeological sites (white dots) near DVF. Insert figure shows location of the DVF. Abbreviations: DPS - Dongpingshan, JS - Jinshan, HTS - Haotianshan, XJYS - Xiaojiayaoshan, FHS - Fenghuangshan, PLS - Pailoushan, GLS - Gelaoshan, LWS - Langwoshan, HS - Heishan. B: Aerial view of Dongpingshan volcano.

2. Sampling site and methods

Dongpingshan volcano is a scoria cone within the DVF, and it has a summit crater ~250 m in diameter (Fig. 1B). There is an outlet to the southeast of the volcano, which may have been developed by outpourings of late-stage lava flows. A scoria quarry is present on the western flank of the cone, and loess sediments occur within the scoria deposits (Fig. 2A). Notably, at Dongpingshan volcano (Fig. 2A), there are no

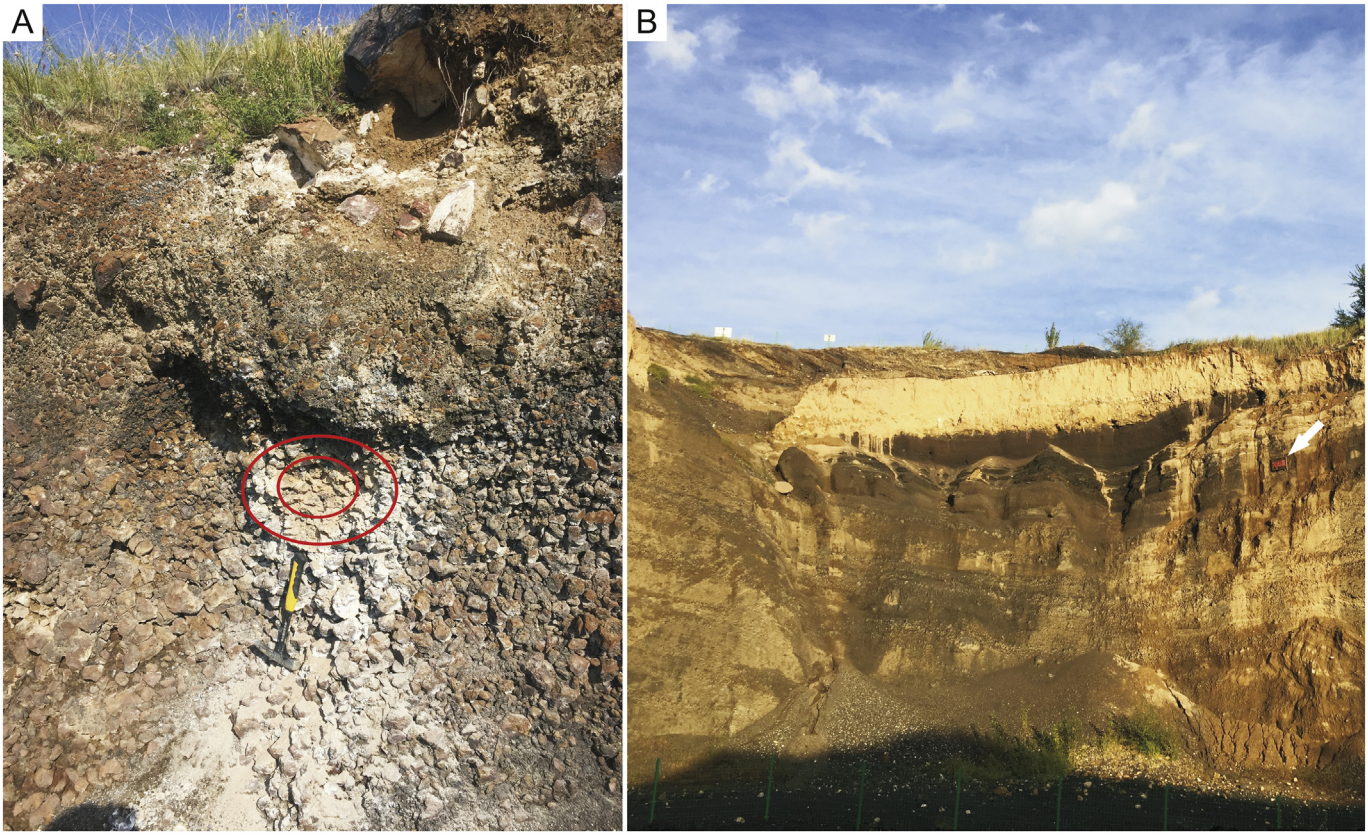

Fig. 2. A: Sampling exposure at Dongpingshan volcanic cone showing loess deposits enclosed within the scoria deposits. The inner red circle represents the original unaffected loess, and the outer red circle represents loess baked by hot scoria. B: Tephra exposure at Jinshan volcano where the scoria fall deposits are covered by thick loess deposits. The board pointed by arrow is about 30*40 cm.

thick loess deposits overlying the scoria, unlike Jinshan volcano (Fig. 2B). The scoria in the exposure at Dongpingshan are composed predominantly of well-sorted brown to black lapilli.

Loess sediments enclosed within the scoria deposits were collected for radiocarbon dating. The bulk organic material and insoluble organic component were dated by accelerator mass spectrometry (AMS) at the Beta Analytic Radiocarbon Laboratory, Florida, USA (Table 1). The radiocarbon ages were calibrated using the IntCal13 curve and the calibrated ranges are reported as two standard deviations (Reimer et al., 2013).

3. Results and discussion

At the sampled exposure of Dongpingshan volcanic cone, loess sediments within the scoria fall deposits are clearly visible (Fig. 2A). The inner part of the loess deposits has retained its original color, while the external part has been ash-baked to some degree. This configuration indicates that loess sediments were encased during eruption of Dongpingshan volcano, and that they can be regarded as having been buried *in situ* by still-hot pyroclastic deposits and are not the product of re-working of the surface sediments after the deposition of the Dongpingshan scoria deposits. Therefore, the age of the encased loess sediments should not be younger than the age of the surrounding scoria fall deposits, and it can be used to date the eruption of Dongpingshan volcano.

Commonly, charcoal can be buried in volcanic fall deposits or pyroclastic density currents, if plentiful vegetation (predominantly trees) existed around the eruptive center; thus, charcoal may be an important source of organic material for dating relatively young prehistoric eruptions in the area (Lavigne et al., 2013; Liu, 1999; Oppenheimer et al., 2017). Pollen studies of deposits of the Chinese Loess Plateau since the Last Glacial Maximum indicate that herbaceous plants were the dominant vegetation component of the region (Jiang et al., 2013). This explains why there has been no radiocarbon dating of wood charcoal in the pyroclastic deposits of the DVF area, which has hindered the development of a precise chronology of the prehistoric volcanic eruptions in the area.

A Holocene loess-paleosol sequence is common within the Loess Plateau (Zhou et al., 1994). Based on the geomorphological evidence that the volcanic rocks in the DVF are covered by thick loess deposits, several studies have concluded that the volcanic eruptions of the DVF ended before the deposition of the local loess sediments (Yin, 1976; Zhou et al., 1982). However, in this study, we have

Table 1
Radiocarbon ages for the Dongpingshan eruption. The results were calibrated using the IntCal13 curve (Bronk Ramsey, 2017; Reimer et al., 2013).

Site	Beta code	Sample type	^{14}C age (yr BP)	Calibrated age (cal yr, 95% probability)
Dongpingshan	509263	Organic sediments	6350 ± 30	7332–7240, 7219–7175, 7414–7389, 7374–7355
	521451	Insoluble organics	6380 ± 40	7420–7250

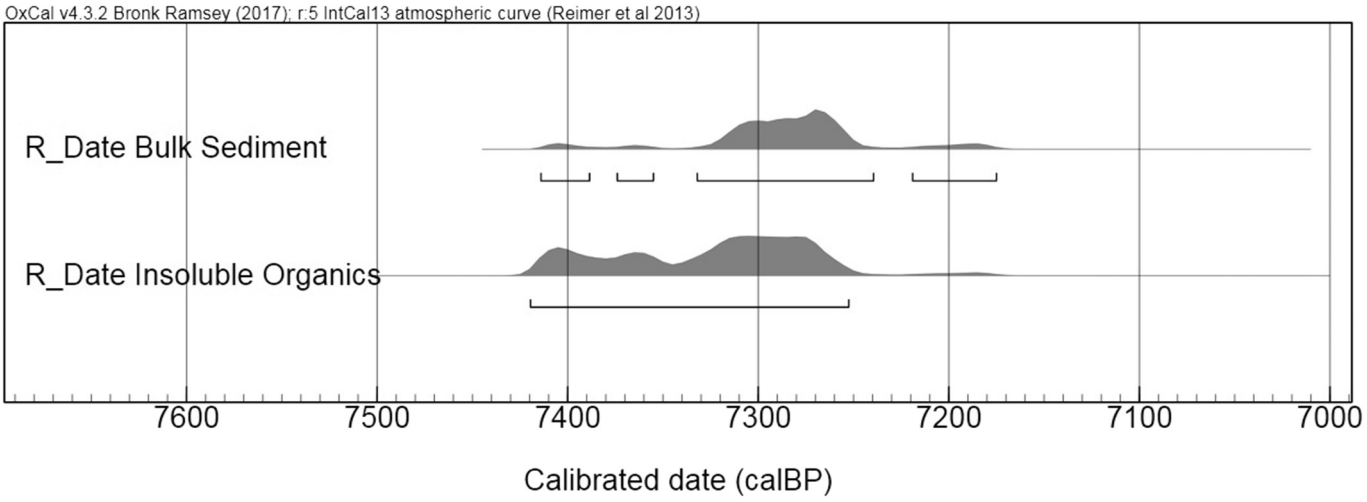

Fig. 3. Radiocarbon dating results (95.4% probability, bulk organic sediment and insoluble organics) for the Dongpingshan scoria fall deposits.

demonstrated the absence of loess sediments covering the scoria deposits of Dongpingshan volcano (Fig. 2A). Therefore, the use of geomorphological evidence to determine the timing of younger eruptions is invalid.

Radiocarbon dating requires organic materials, which are rare in volcanic rocks. However, the widespread occurrence of organic loess deposits within the DVF may provide valuable material for radiocarbon dating. Radiocarbon dating of the organic material and insoluble organic fraction of the loess sediments from the sampled Dongpingshan exposure gave an age of ~7300 cal yr BP for the Dongpingshan eruption (Fig. 3 and Table 1). The insoluble organic fraction produced a result similar to that of the bulk organic fraction; moreover, radiocarbon dating of this fraction of loess deposits may produce a true age for the organic material (Wang et al., 2014; Zhou et al., 2007). We are confident that the dating results presented herein are reliable, and they demonstrate that the most recent eruption of the DVF was not older than ~7300 cal yr BP. Therefore, the DVF cannot be considered as an extinct volcanic field.

4. Summary

To date, K-Ar and OSL geochronometric methods have been used to date the volcanic eruptions within the area that are older than 50 ka (Chen et al., 1992; Zhao et al., 2015). The results of this study confirm the occurrence of a Holocene eruption within the DVF, thereby showing that it is presently dormant but not extinct. This implies that there exists the potential in the future for possible renewed eruptive activity, which would pose some level of volcanic hazard for this densely populated area. Because it is difficult to reliably reconstruct the history of Late Pleistocene to Holocene volcanic eruptions in the region, the radiocarbon dating of loess sediments contained within volcanic products can provide a relatively precise method for determining the ages of these young eruptions (<50 ka). Therefore, we suggest that a more comprehensive chronological sequence for volcanic eruptions in and around the DVF can be obtained using the combination of ^{14}C, K-Ar (Ar-Ar), and OSL dating.

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