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New age constraints for hominid footprints found on Jeju Island, South Korea

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ABSTRACT

In 2004 numerous hominid footprints, along with diverse animal footprints, were found in the Late Quaternary strata of Jeju Island, South Korea. However, the age of the sediments in which the footprints were found is still controversial. Previous age estimates included radiocarbon ages of ca. 15,000 yr BP (Late Pleistocene) and quartz optically stimulated luminescence ages of ca. 7000 yr BP (mid-Holocene). In this study we report on 11 AMS ^{14}C dating results from a new set of samples collected from the footprint-bearing strata and from associated sediments. Despite some variations and age reversal, all samples collected from the footprint-bearing strata yielded ^{14}C ages of late Pleistocene. These ages are comparable with previous radiocarbon dating results. Furthermore, the presence of the proboscidean footprints attributable to woolly mammoths in the footprint-bearing strata supports the radiocarbon dating results. Based on the new radiocarbon dates and the presence of the alleged mammoth footprints, the age of the hominid footprints found at Jeju Island is thought to be late Pleistocene (about 19,000–25,000 cal yr BP). Therefore, this is the second discovery of hominid footprints dated to the Pleistocene age in Asia, and the first to be discovered in Korea.

1. Introduction

To date, Pliocene to Pleistocene hominid footprints have been reported from every continent except Antarctica (Lockley et al., 2008, and references therein). Such records have provided important information on hominid evolution and dispersal (Kim et al., 2007). In 2004 hominid footprints were reported at the coastal area of Jeju Island, South Korea (Kim et al., 2004). These hominid footprints and associated diverse bird and mammal tracks were found in tuffaceous sediments exposed along the shoreline. In 2005, the Cultural Heritage Administration of Korea designated this fossil track site as Natural Monument No. 464 because of its geological and archaeological importance. However, dating the age of the footprint-bearing strata has proved a lengthy and problematic task. Although radiocarbon and optically stimulated luminescence (OSL) dating methods were used to estimate the age of the track-bearing horizon, the results did not agree, ranging between ∼7 ka and ∼15 ka and leaving the age of the hominid footprints controversial (Cho et al., 2005; Kim and Kim, 2006). This study evaluated the previous age estimates and reports a series of new radiocarbon dates obtained with the goal of clarifying the age of the hominid footprints found on Jeju Island.

2. Geological setting

Jeju Island, the largest island of Korea, is located about 90 km south of the Korean Peninsula (Fig. 1). It was formed in several stages by volcanic activity from about 1 million to a few thousand years ago and, as a result, is almost entirely composed of volcanic rocks, mainly trachyte, trachyandesite, alkali basalt, and volcaniclastic rocks (Won, 1976; Sohn and Chough, 1992). Mount Halla, with a height of 1950 m, is a shield volcano located near the centre of the island. More than 360 parasitic scoria cones are present on the island, composed of cinder cones, tuff rings, and tuff cones. The basement rocks of Jeju Island are Jurassic-Cretaceous granites and overlying Cretaceous-Tertiary rhyolitic tuff. Relatively less viscous basaltic lava flows intermittently produced more than 120 lava tubes which are widely distributed along the coast.

The geologic sequence of the Hamori-Songaksan area, near the location of the fossil footprints, can be divided into five units: the Kwanghaeak Basalt, unnamed strata, Songaksan Tuff, Hamori Formation, and sand dune, in ascending order (Kim and Kim, 2006). The lowest Kwanghaeak Basalt is characterized by

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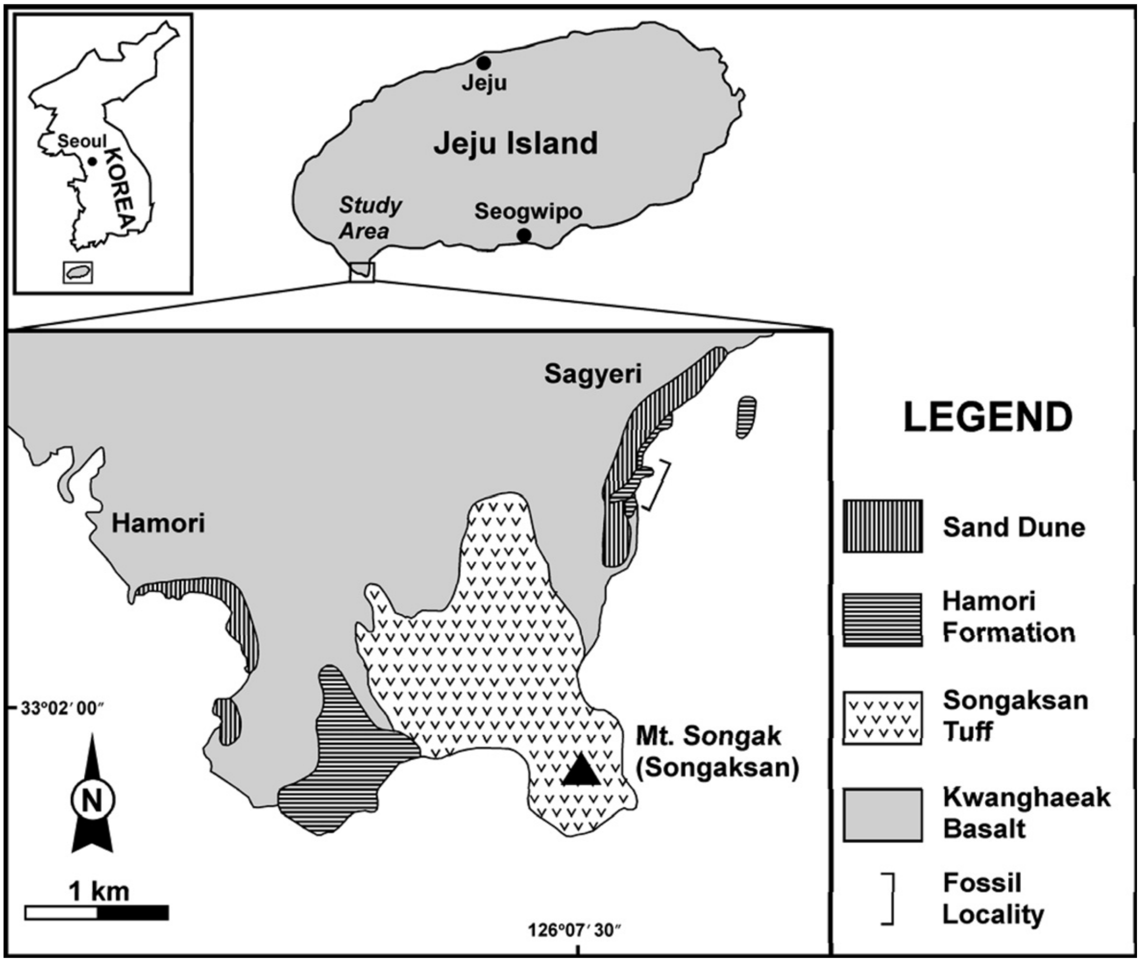

Fig. 1. Simplified geologic map of the southwestern part of Jeju Island, South Korea (modified from Park et al., 2000).

abundant olivine phenocrysts and acicular feldspar laths, and occurs along the seashore. The overlying unnamed strata mainly consist of reworked volcaniclastic sediments. The Songaksan Tuff is mainly composed of thin-bedded tuff with abundant mega-ripple bedforms, mostly formed by pyroclastic surges and attendant airfall on a subaerial setting (Chough and Sohn, 1990; Sohn et al., 2003). The Songaksan Tuff is unconformably overlain by reworked volcaniclastic deposits of the Hamori Formation, which are composed of basaltic pebbly sandstone, basaltic tuffaceous sandstone, and siltstone (Sohn et al., 2003). On the basis of detailed logging of the Hamori Formation, Sohn et al. (2003) indicated that this formation was deposited in a high-energy near-shore environment during and after the eruption of the Songaksan tuff ring. However, Kim et al. (2009) suggested that the hominid footprints in the Sagyeri area were formed on a shallow shoreline environment, especially a semi-closed lagoon or littoral flat setting (Fig. 2).

3. Material and analytical methods

To determine the stratigraphy and age of the footprint-bearing strata, a 3.0 m-deep trench was dug near the fossil footprint site (about 80 m southwest of the footprint site; N33°13′01.89″, E126°17′35.83″) (Figs. 1 and 3). The trench section is divided into the Kwanghaeak Basalt, the footprint-bearing strata, Hamori Formation, palaeosol layer, and sand dune in ascending order (Fig. 3). The footprint-bearing strata can be subdivided into basal conglomerate, brown mud, volcanic sand, and alternating layers of light and dark grey silt. Eleven sediment samples for radiocarbon dating were taken from the vertical section of the trench (Fig. 3) and dated by accelerator mass spectrometry (AMS) at the Rafter Radiocarbon Laboratory, New Zealand.

4. Results

Table 1 lists the results of the 11 AMS ^{14}C datings of bulk sediment samples carried out in this study. Radiocarbon dates were calibrated to calendar years using the terrestrial INTCAL09 data set by means of the CALIB program 6.0 (Stuiver and Reimer, 1993; Stuiver et al., 1998). The age determinations reveal that the footprint-bearing strata are of late Pleistocene age (ca. 19,000–25,000 cal yr BP) except the uppermost JS1-9 sample (9700–10,160 cal yr BP). However, they show some variation and age reversal, possibly caused by organic matter input from different sources. The radiocarbon ages of two samples collected from the Hamori Formation and overlying palaeosol layer are 4100–4800 cal yr BP and 2750–2780 cal yr BP, respectively. The large age difference between the footprint-bearing strata and overlying Hamori Formation indicates that there is an unconformity beneath the Hamori Formation. Moreover, the significantly different $\delta^{13}C$ values of the two formations imply that their organic matter might have derived from different sources.

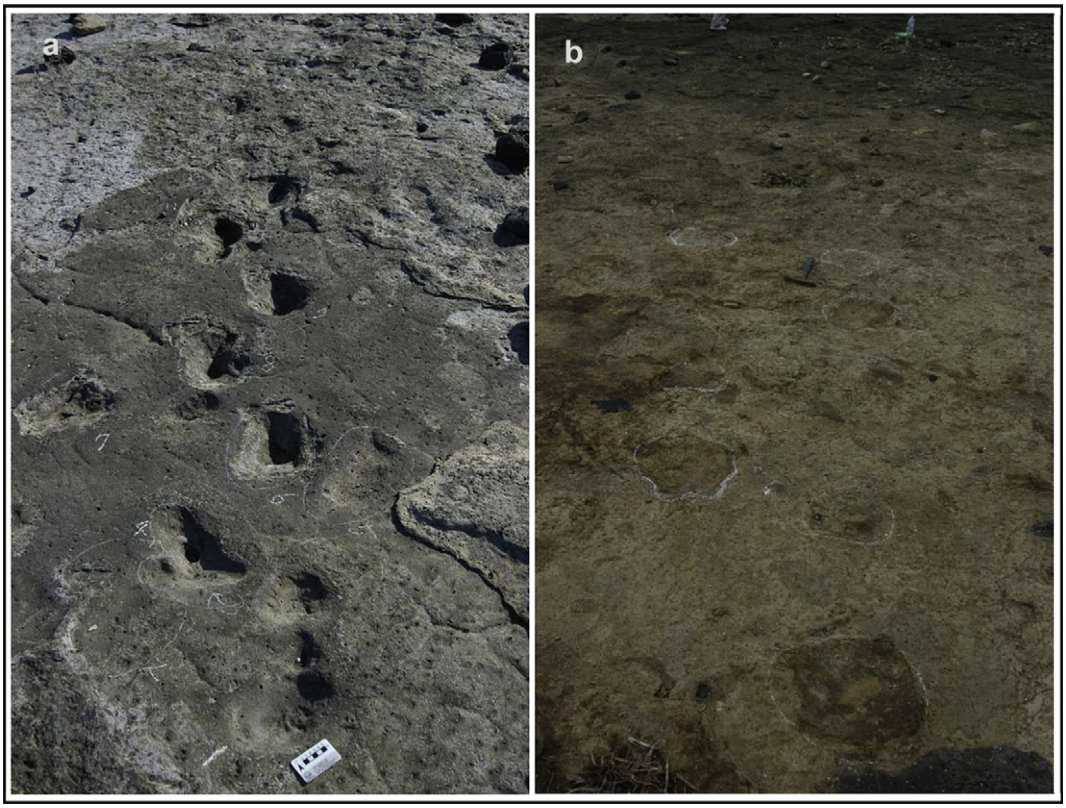

Fig. 2. (a) Human and (b) Proboscidean (probably woolly mammoth) footprints from the Late Pleistocene of Jeju Island, South Korea.

5. Interpretation and discussion

5.1. Geological age constraints

Although accurate dating of bulk sediment is complicated by the presence of multiple organic carbon fractions, each with a potentially different ^{14}C activity, radiocarbon dating of bulk sediment has long been used when reliable materials, such as wood, charcoal, or plant macrofossils, are not available for analysis. In this study, samples collected from the footprint-bearing strata show a large ^{14}C age difference with age reversal. Compared to other samples from the footprint-bearing strata, the uppermost sample (JS1-9) has much younger age of ca. 9700–10,160 cal yr BP, suggesting that the upper part of these strata, just beneath the Hamori Formation, was significantly affected by the input of younger carbon. The presence of numerous rootlets supports such an interpretation. The radiocarbon ages from samples covering the lower 1 m (JS1-1–JS1-3) have relatively younger ^{14}C ages than samples lying above them. This could be related to contamination associated with the input of modern carbon. At the bottom of the trench, a lot of modern shell fragments were found, suggesting an inflow of seawater through a cavity. Furthermore, the relatively high $\delta^{13}C$ values (approximately −31 to −27‰) of the lower samples also indicate possible contamination by younger carbon. Despite the relatively large age differences and stratigraphic age reversal, all samples from the hominid footprint-bearing strata show radiocarbon ages of late Pleistocene (ca. 19–25 ka), which are similar to the ^{14}C ages obtained for the humin fraction by Cho et al. (2005).

In previous work, Park et al. (2000) and Sohn et al. (2003) reported that the surrounding geology of the Hamori-Songaksan area is composed of the Kwanghaeak Basalt, unnamed strata, Songaksan Tuff, Hamori Formation, and sand dune in ascending order. However, they thought that the Quaternary succession in the Sagyeri area consists of, from bottom to top, the Kwanghaeak Basalt, Hamori Formation, and sand dune. Based on the above stratigraphic classification, Cho et al. (2005) regarded the fossil footprint-bearing layer in the Sagyeri area as the Hamori Formation. However, Kim and Kim (2006) insisted that the footprint-bearing layer should be correlated with the unnamed strata in the Hamori-Songaksan area.

The age of the Hamori Formation has been the subject of numerous studies and much debate in recent years. Molluscan shell samples collected from the Hamori Formation yielded radiocarbon ages ranging from ca. 3000 to 4000 yr BP (Sohn et al., 2003; Cho et al., 2005) and $^{230}U–^{234}Th$ ages ranging from ca. 3700 to 4300 yr BP, which are consistent with radiocarbon data (Cheong et al., 2006). Recently a quartz OSL age estimate of 5.1 ± 0.3 ka was reported for the Hamori Formation (Cheong et al., 2007). Cheong et al. (2007) also reported a quartz OSL age of 7.0 ± 0.3 ka from the Songaksan Tuff, underlying the Hamori Formation. Therefore, it is reasonable to assume that the Hamori Formation is of mid-Holocene age with a maximum age of about 7.0 ka, and the footprint-bearing strata should not be correlated with the Hamori Formation, but with the unnamed strata at the west coast of Mt. Songak.

To estimate the age of the footprint-bearing layer, Cho et al. (2005) performed radiocarbon and OSL datings of samples collected from above and below the footprint-bearing layer. They reported OSL ages of 6.8 ± 0.3 ka and 7.6 ± 0.5 ka for the upper and lower layers, respectively, and concluded that the hominid footprints were formed ca. 7000 yr BP. However, the radiocarbon dating results showed much older and more complicated ages. The radiocarbon ages for humin and humic fractions range from $10{,}901 \pm 60$ yr BP to $15{,}161 \pm 70$ yr BP, and from 8098 ± 50 yr BP to

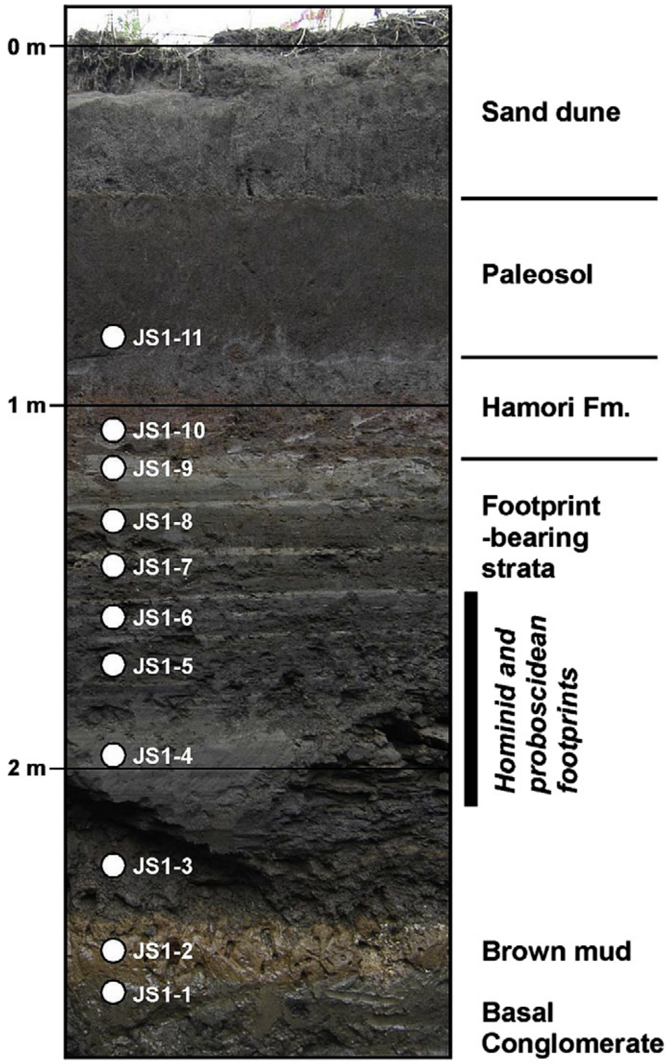

Fig. 3. The 3 m-thick trench section, showing the location of samples for radiocarbon dating.

9289 ± 90 yr BP, respectively (Cho et al., 2005). The humin ages are significantly older than the ^{14}C ages obtained on humic samples, and both ^{14}C ages for humin and humic fractions are older than the OSL ages. Despite such contradictory results between the different dating methods, Cho et al. (2005) decided the footprint-bearing layer to be ca. 7000 yr BP based on the OSL ages, but without sufficient justification. When comparing the ^{14}C dates obtained in this study, however, the ^{14}C ages for humin fraction are more reliable than the OSL ages. The humin fraction is the more stable organic compound and can be considered a reliable material for ^{14}C dating in soils when wood, charcoal, or plant macrofossils are not available for analysis (McGeehin et al., 2001; Pessenda et al., 2001). To summarize the dating results and stratigraphy of the fossil footprint site, the hominid footprints found on Jeju Island are thought to be late Pleistocene in age. This is the second discovery of hominid footprints dated to the Pleistocene age in Asia (Zhang and Li, 2002) and the first in Korea. The much younger OSL ages previously reported (Cho et al., 2005) cannot be explained here, but it might have been due to the presence of undesirable OSL characteristics from volcanically derived materials (Tsukamoto et al., 2003). However, further detailed study is needed to understand the OSL dating results.

Table 1
Radiocarbon ages from the Sagyeri section near the fossil footprint site, Jeju Island.

Sample code	Laboratory code	Material	δ^{13}C (‰)	^{14}C age (yr BP)	Calibrated age ranges, 2σ (yr BP)
JS1-1	NZA29540	sediment	−27.2	17,612 ± 95	20,510–21,370
JS1-2	NZA29504	sediment	−28.3	17,990 ± 75	21,190–21,760
JS1-3	NZA29541	sediment	−30.8	17,724 ± 95	20,550–21,480
JS1-4	NZA29539	sediment	−30.9	19,790 ± 170	23,150–24,230
JS1-5	NZA29543	sediment	−35.3	21,160 ± 110	24,920–25,720
JS1-6	NZA29544	sediment	−32.4	16,342 ± 95	19,000–19,870
JS1-7	NZA29508	sediment	−35.8	17,301 ± 75	20,250–21,090
JS1-8	NZA29542	sediment	−32.3	16,970 ± 100	19,620–20,420
JS1-9	NZA29639	sediment	−32.2	8842 ± 55	9700–10,160
JS1-10	NZA29546	sediment	−25.8	3947 ± 85	4100–4800
JS1-11	NZA29526	palaeosol	−23.1	2662 ± 15	2750–2780

Despite of the short history, paleoanthropological research in Korea has produced a good number of hominid fossils, lithic artefacts, and Pleistocene faunal remains. Due to acidic soils in the southern region of the Korean Peninsula, however, hominid bone preservation at open-air sites is poor in South Korea. Accordingly, the majority of hominid fossils and Pleistocene faunal assemblages have been found in North Korea or cave sites (Norton, 2000 and references therein). Thus, the results of this study can provide important information on the timing of the migration and settlement of modern human into Jeju Island. The origin and dispersal of modern *Homo sapiens* in East Asia are not exactly known because of limited record of hominid fossils systematically studied, though Oppenheimer (2003) provided a map of modern human dispersals throughout the world. Park (1999) regarded that the *H. sapiens* arrived at northeast Asia dispersed into the Korean Peninsula and Japan during the Late Pleistocene (24–20 ka). Based on the Y-chromosomal DNA analysis from 11 ethnic groups in east Asia, Jin et al. (2003) suggests that Korean people were originated mainly from north, and partly from south. Recent study on the migration route of *H. sapiens* in the Korean Peninsula also indicates two ways; one way from the Manchuria and the other from south China (Song et al., 2004). The early *H. sapiens* appear to have migrated into Jeju Island when it was connected to the Korean Peninsula and the Chinese mainland during the low sea-level stand. But, further detailed study is needed to clarify the timing and migration route of modern *H. sapiens* in Jeju Island.

5.2. Other vertebrate footprints and their implications

Along with the hominid footprints many diverse vertebrate footprints were also found, including artiodactyl, proboscidean, carnivore, and avian footprints. This is first find of such footprints in Korea (Kim et al., 2004, 2009). The proboscidean footprints found here can provide another line of evidence for the age of hominid footprints.

One distinct track of proboscidean prints, composed of four sets of manus and pes prints, was recognized. The manus impressions are about 40 cm long and 36 cm wide, and the pes impressions are approximately 30 cm both in length and width (Kim et al., 2009). The stride length is about 245 cm (Kim et al., 2009). Based on the size and shape of tracks and the stride length, these can be interpreted as proboscidean footprints, probably produced by woolly mammoth. On the Korean peninsula, *Mammuthus primigenius* was recorded from northeastern North Korea (Hamkyung Province; ∼41°N; Park, 1988) and also mentioned from the Jungwon area in the middle part of South Korea at ∼37°50′N (Cho and Woo, 2004). Therefore, these prints are the first discovery on Jeju Island and the most southerly record of proboscidean footprints in Korea.

During the Last Ice Stage, woolly mammoths were very widely distributed across northern Eurasia into North America. They ranged mostly within the latitudes of 40–75°N (Kahlke, 1999), but reached as far south as approximately 35°N in China and Japan (Takahashi et al., 2006, 2007). These large mammals died out around the time of the last glacial retreat, as part of a mass extinction of megafauna in northern Eurasia and North America. Although the latest mammoths have been dated to ca. 9700 yr BP in mainland Siberia, and to ca. 3700 yr BP on Wrangel Island in the Arctic Ocean (Stuart et al., 2002; Guthrie, 2004), it is generally known that woolly mammoths disappeared entirely and rather suddenly from Europe and most of northern Asia shortly before ca. 12 ka (Stuart, 1991; Stuart et al., 2002). The extinction of the mammoth was probably caused by a combination of factors, such as overkill by hunting, global warming in the Late Glacial (since ca. 15,000 yr BP), and the disintegration of landscapes suitable for mammoths throughout the Late Pleistocene (Stuart, 1991; Kuzmin and Orlova, 2004). Suitable habitats for herbivorous megafauna, especially for mammoths, are thought to have rapidly decreased with the expansion of forest vegetation after the Last Glacial Maximum (LGM) (Kuzmin and Orlova, 2004).

Research on multi-proxy data of paleoclimate change at Jeju Island indicated that the island was coldest around 18,000 cal yr BP, which corresponds to the LGM, and that the last major deglaciation began around 14,000 cal yr BP, representing a climate shift from cold to warm conditions (Lee et al., 2008). Previous pollen studies found that *Artemisia*-dominated grassland with patches of cool temperate deciduous broadleaf forest developed under cold and dry conditions on Jeju Island during the LGM (Chung, 2007). Thus, the woolly mammoths could survive on Jeju Island during the LGM, but disappeared with the onset of the last deglaciation due to the reduction of grass-dominated steppe-like habitats. The proboscidean footprints attributable to woolly mammoths correspond with the paleoclimate and paleovegetation change on Jeju Island and support the radiocarbon dating results obtained in this study.

6. Conclusion

To estimate the age of hominid footprint-bearing strata, 11 AMS ^{14}C datings were carried out on bulk sediment samples collected from the footprint site. Despite some variation and age reversal, due to the complex nature of the footprint-bearing volcaniclastic deposits, most samples from the footprint-bearing strata show radiocarbon dates of the Late Pleistocene age. The proboscidean footprints found in the footprint site also provide decisive evidence on the age of the hominid footprints. The proboscidean footprints are thought to have been formed by woolly mammoths which disappeared with the onset of the last deglaciation. Based on the new radiocarbon dates and the presence of the alleged mammoth footprints, the age of the hominid footprints found on Jeju Island is thought to be late Pleistocene. This late Pleistocene (ca. 19,000 to 25,000 cal yr BP) record of hominid and animal footprints is expected to provide valuable information on hominid evolution and dispersal during the Upper Palaeolithic age.

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