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Deposition and weathering of Asian dust in Paleolithic sites, Korea

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ABSTRACT

Paleolithic stone artifacts in Korea typically occur in brown clay–silt (BCS) sequences. The origin and depositional environment of these sequences are important for reconstructing the paleoenvironment as well as for establishing chronologies of artifact-bearing stratigraphic units. We investigated four BCS-bearing sections in foothills and river and marine terraces in Korea by applying quantitative mineralogical, geochemical, microtextural, and K–Ar isotopic methods. In all four sections, the lower units are colluvial and fluvial deposits strongly influenced by diverse local lithology, whereas the upper units are characterized by BCS units. Mineralogical/geochemical compositions, grain sizes, and colors converge into common properties in the upper BCS units in all sections. These common properties are consistent with the eastward trends of increasing weathering degree and grain size fining throughout the loess–paleosol sections of the Chinese Loess Plateau (CLP). K–Ar detrital ages of the sections also converge upward into a narrow range similar to the age ranges of the loess and paleosols in the CLP. The top BCS unit in the Jeongok section, the thickest section, is underlain by an additionally weathered BCS unit, with strong red chroma indicating a change from warm to cold climate. We did not observe any clear evidence of climatic changes in other thinner sections, which may be due to a superposition of cold-stage accumulation and warm-stage deep weathering. The common properties of the BCSs in Korean sections and their relationship to the CLP loess and paleosols indicate widespread deposition of Asian dust and subsequent weathering in the late Quaternary, forming BCS sequences. In this respect, the BCS sequences investigated here are considered to be the additionally weathered equivalents of the CLP loess–paleosol sequences, having been exposed to the high annual precipitation of the Korean Peninsula. Given the wide distribution of BCS sequences at Paleolithic sites throughout the Peninsula, the findings of this study are important for the ongoing debate surrounding the depositional environments of the Paleolithic deposits, and provide a foundation for the establishment of the chronological framework of the Paleolithic artifact-bearing layers and lithic assemblages.

1. Introduction

Asian dust blown from the deserts of western China and southern Mongolia migrates eastward through China, Korea, Japan, and the North Pacific during the spring season (Fig. 1) (Uematsu et al., 1983; Asahara et al., 1999; Chun et al., 2001; Arimoto et al., 2004; Jeong and Chun, 2006; Zdanowicz et al., 2006; Jeong, 2008). Dust concentration in the air mass is progressively lowered by dispersion and deposition during transportation. Quaternary terrestrial deposits from the Asian dust are distributed downwind of the source regions. These are particularly thick near the Chinese deserts forming the Chinese Loess Plateau (CLP), which exceeds 300 m thickness near Lanzhou (Liu et al., 1988; An et al., 1991; Ding et al., 2001; Kemp et al., 2001; Porter, 2001; Sun et al., 2001; Guo et al., 2002; Jeong et al., 2008; Maher et al., 2009; Jeong and Lee, 2010; Jeong et al., 2011). Because the Korean Peninsula is located in the middle of the Asian dust transport route, deposition of dust particles is likely widespread, but in thin layers.

Brown clay–silt (BCS) sequences of uncertain origin are common sedimentary units in Paleolithic sites throughout the Korean Peninsula. Paleolithic artifacts including hand axes of unknown age have been excavated from the BCS sequences. These BCS sequences are distinguished from the underlying units by their fine silty to

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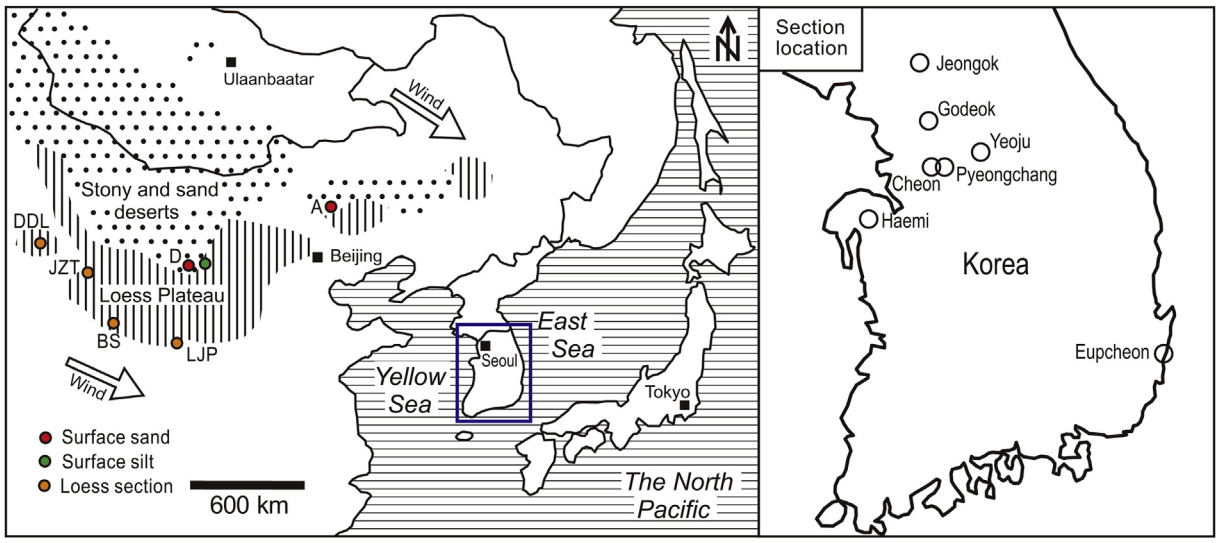

Fig. 1. Locations of the brown clay–silt (BCS) sedimentary sections in Korea, the sites of the loess and paleosol sections in the Chinese Loess Plateau (CLP), and surface silt/sand sites. Arrows indicate the dominant wind directions in the movement of Asian dust. DDL: Dadongling, JZT: Jiuzhoutai, BS: Banshan, LJP: Liujiapo, A: Sandy soil sample near Duolun, Inner Mongolia, China, D: Sandy soil sample near Mu Us, Inner Mongolia, China. Surface silty soil on the CLP near Yulin, Shaanxi, China. Chemical data for bulk samples from Pyeongchang (Lee and Yi, 2002), Haemi (Yoon et al., 2011), and Yeoju (Lee, 2007) were used in Fig. 7 for comparison.

clayey characteristics and reddish- to yellowish-brown color. The BCSs have frequently been observed in investigations (Naruse et al., 1985; Park, 1985; Mizota et al., 1991). An eolian origin was proposed with the discovery of the Aira-Tanzawa (AT) tephras at the top of the BCS profiles of many Paleolithic deposits (Yi et al., 1998; Yi, 2000).

Significant numbers of various Paleolithic artifacts important to the understanding of modern human evolution and migration in eastern Asia have been excavated from the BCSs in the last four decades. The origins, paleoclimates, and ages of the BCSs, which are widely distributed across the Korean Peninsula, have become a major subject of investigation in Korean archaeology. The origin of the BCSs has been intensively investigated by many authors who have measured color changes, grain sizes, magnetic susceptibility, and major and trace element geochemistry (Shin et al., 2004, 2005; Yoon et al., 2007, 2011; Yu et al., 2008; Kim et al., 2011). Most previous studies suggested an eolian origin for the BCSs, correlating them with the CLP loess and paleosols (Shin et al., 2004, 2005; Yoon et al., 2007, 2011). The BCSs, however, are darker in color and have higher clay content than the CLP loess and paleosols, and carbonates are absent. Danhara et al. (2002) reported that the thick Jeongok section (thickness $>\sim$7 m), one of the Korean BCSs, was formed by a series of eolian depositional events. On the basis of the discovery of the AT tephra (22–25 ka), and the controversial finding of the Kikai-Tozurahara (K-Tz) tephra ($\sim$90–95 ka), they argued that the bottommost layers overlying the basalt are likely to be older than 300,000 years. Consensus on the eolian origin of the BCS sediments, however, has not been reached. Arguments skeptical of the eolian origin have been presented (e.g., Kim et al., 2002, 2004), and the evidence that seems to indicate a fluvial origin of the BCSs has also been reported (e.g., Yi, 2011; Yi et al., 2011).

The identification of eolian features is not straightforward in the geological and geomorphological environments of the Korean Peninsula, unlike in the CLP. Granitic and metamorphic bedrocks were significantly weathered to form a deep saprolite–soil profile under temperate humid climate conditions (Jeong and Kim, 1993; Jeong and Lee, 1998; Jeong, 2000; Jeong et al., 2006). The high relief mountain topography causes mass movement of the soils on the steep slopes, surface erosion, and possible mixing of eolian particles transported over long distances and local particles. These topographic features have given Asian dusts falling onto the Korean Peninsula little chance to accumulate as a large-scale sedimentary body, such as in the continental plains of Central Asia, China, Europe, and North America (Muhs, 2007). In addition, the fine eolian particles transported from the arid source regions may have been subjected to chemical weathering after deposition. The well-established stratigraphy of the CLP (Kukla and An, 1989; An et al., 1991) cannot be readily applied to the Korean sections because the general thinness (commonly $<\sim$2 m) of the BCS sequences results in the superposition of glacial and interglacial records. Even stratigraphic correlations among the different Korean sections are difficult because of their widely varying thicknesses, the absence of a universal marker layer, and their scattered distribution across narrow low-lying terrain among steep hills (Shin et al., 2004, 2005; Yoon et al., 2007, 2011; Yu et al., 2008; Kim et al., 2011).

The goal of this study was to provide comprehensive evidence for the origin of the BCS sequences in Korea by applying a range of analytical methods to investigate their physicochemical properties as well as their temporal and spatial variations. Our investigative strategy was three-fold. The mineralogy of individual silt particles in the BCS sequences and their weathering textures in thin sections were first analyzed, and secondly quantitative mineralogical, geochemical, and K–Ar isotopic data from the bulk samples were collected. Finally, bulk sample data were integrated with the microscopic data to elucidate the depositional and weathering processes of the BCSs, comparing the results to the equivalent data from the CLP. For this study we focused on three sections within Paleolithic excavation sites (Jeongok, Godeok, and Cheon) and one section in a paleoseismic trench site (Eupcheon) (Fig. 1). More detailed analysis has been done in the Jeongok section because of its considerable thickness ($\sim$7 m). It is also thought to be the site where Acheulean stone tools were first found in Asia, and thus has a long history of archaeological excavations (Yi and Clark, 1983; Bae et al., 2001; Yi et al., 2011).

2. Sedimentary sections and samples

2.1. Jeongok section

The regional geology of the upper reach of the Hantan River is dominated by Jurassic and Cretaceous granitic rocks (Hwang and