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New research on the origin of mottled clay in Quaternary basins in the coastal area of south China

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ABSTRACT

Last Glacial Maximum (LGM) mottled clay occurs widely in Late Quaternary basins in south China coastal areas. Current research attributes its origin to exposure weathering of Late Pleistocene marine/fluvial deposits during the LGM. However, field data suggest that this is not the case as there is no gradual transition in lithology, grain size, structure and material composition among these layers. Instead, the mottled clay possesses sedimentary characteristics of exotic dust. In this study, three typical drill cores in the Pearl River Delta were studied using grain size analysis, diffuse reflection spectroscopy (DRS) and geochemical analysis to ascertain the clay's sedimentary characteristics and origin. Grain size distribution patterns and parameters of the mottled clay were similar to those of a typical loess, indicating aeolian origin. In DRS curves, the peak height of hematite > goethite, indicating that the mottled clay had not experienced strong hydration and constitutes a continental product. This conforms to a typical loess but differs from the underlying marine/fluvial deposits. The chemical composition of the mottled clay was homogeneous in the vertical and planar directions. Upper continental crust (UCC) normalized curves of major and trace elements of the mottled clay were close to the average UCC and were consistent with typical aeolian deposits. The spatial and temporal distribution characteristics and relationship with the underlying layer suggest that the mottled clay was a loess-like deposit during the LGM and its mottled structure originated from strong modification of oxidation during the postglacial period after homogeneous dust had accumulated.

1. Introduction

One or more layers of yellow silt, sometimes exhibiting a yellow color mixed with red and grey, is referred to as "mottled clay" or 'mixed color clay" (Zhao, 1980; Huang, 1982; Li et al., 1984; Wei and Wu, 2011; Xie et al., 2014). It generally developed in the Late Quaternary sedimentary basins in coastal areas of south China, such as the Pearl River Delta (PRD), Lianjiang Plains, Hanjiang Delta, Fujian coastal basins and shallow shelf basins north of the South China Sea, etc. (Fig. 1). This layer usually formed during the regressive period between two high sea levels, but affected by seawater disturbances, the older layer was often destroyed. Only the mottled clay formed during the later stage of the Late Pleistocene (Q_3^3), i.e., Last Glacial Maximum (LGM), was mostly preserved (Huang, 1982; Li et al., 1984; Long, 1997; Wei and Wu, 2011; Liu et al., 2012; Xie et al., 2014). As carbon-bearing material suitable for dating occurs rarely within the mottled clay layer, its age is often obtained by deduction based on the ages of sediments above and below it. Results from radiocarbon (^{14}C) and thermoluminescence (TL)/optically-stimulated luminescence (OSL) measurements have shown that the age of Holocene (Q_4) black marine mud overlying the mottled clay is ~10 ka (Huang, 1982; Yu et al., 2003; Zong et al., 2009; Wei and Wu, 2011; Xie et al., 2014), whereas the age of underlying Mid-Late Pleistocene (Q_3^2) sediments, characterized by fluvial-marine grey-black clayey to silty sand or marine mud, is between 25 and 40 ka (Huang, 1982; Zong et al., 2009; Liu et al., 2012; Chen et al., 2014; Wang et al., 2015). Thus, the age of the sandwiched mottled clay is estimated to be 25–10 ka (Q_3^3), corresponding to marine isotope stage 2 (MIS 2) (Fig. 2; Huang, 1982; Long, 1997; Zong et al., 2009; Liu et al., 2012; Xie et al., 2014; Wang et al., 2015).

Currently, the mottled clay is mostly regarded as originating from exposure weathering of the sediments on top of the transgression layer of the Late Pleistocene during the LGM (MIS 2), when the sea level was comparatively low (Huang, 1982; Li et al., 1984; Lan, 1996; Long, 1997; Wei and Wu, 2011; Liu et al., 2012; Chen et al., 2014; Waxi et al., 2016). This weathering is believed to have caused the dark grey fluvial/marine deposits to change into a mixed-color clay, i.e., "mottled clay" (Zhao, 1980; Huang, 1982; Li et al., 1984; Long, 1997; Huang and Cai,

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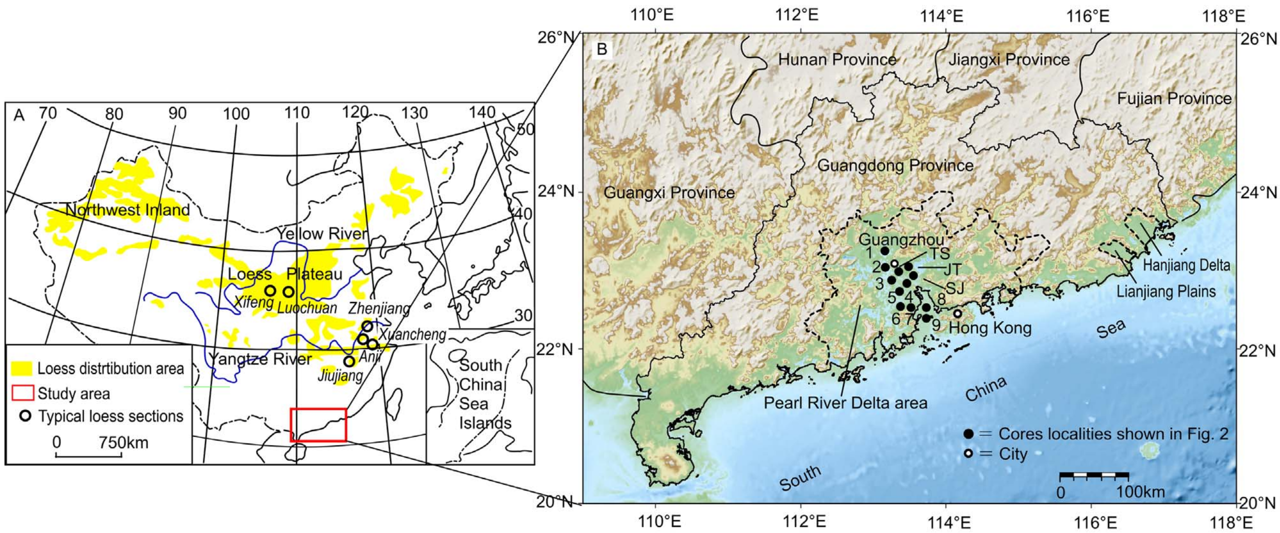

Fig. 1. Geographical location of the study area and drill core distribution sites in the PRD area (modified from Wang et al., 2015). Maps showing (A): Loess distribution in China and locations of typical loess sections mentioned in this paper; (B): Distribution of mottled clay at several core sites in the PRD area. The drill cores marked by letters were the main focus of this study.

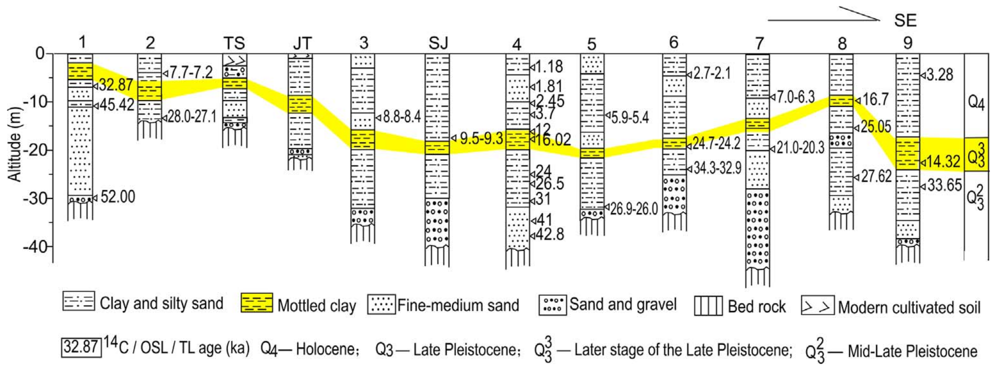

Fig. 2. Late Quaternary stratigraphic correlation in the PRD showing the ages and buried depths of mottled clay, with cores sites shown in Fig. 1 (modified from Wang et al. (2015); No. 1–9 cores from Huang (1982) and Zong et al. (2009)).

2007; Xie et al., 2014). Therefore, the "weathering layer", which is very different from the underlying fluvial/marine sediments in lithofacies, is divided separately in terms of stratigraphic division. It was termed the "Weathering Layer of Lile" by the Department of Marine Geology, South China Sea Institute of Chinese Academy of Sciences (1978) after their research on the Quaternary strata in the PRD, the "Sanjiao Formation" (Q_3^{sj}) by Huang (1982) in his study on the formation and evolution of the PRD and the "Tuopu Formation" (Q_3^{tp}) by Li (1987) in his investigation of the Quaternary strata of the Hanjiang Delta. In addition, this layer corresponds to the upper "Longhai Formation" (Q_3^{lh}) and "Dongshan Formation" (Q_3^{ds}) in the coastal area of Fujian Province (Bureau of Geology and Mineral Resources of Fujian Province, 1985).

Recently, we collected and investigated Quaternary drill core data from the coastal area of south China, especially in the PRD area. Results from these drill cores showed that no obvious weathering transition relationship exists between the mottled clay and its underlying sedimentary layer in terms of lithology, grain size, structure and composition. Instead, the mottled clay is silty, easily raised by wind and similar to typical north China loess, suggesting that it was formed by exotic dust accumulation rather than in-situ weathering of the underlying fluvial or marine deposit.

To ascertain the characteristics and origin of this mottled clay, three representative drill cores from the PRD were selected for further study using laser particle size analysis, diffuse reflectance spectroscopy (DRS) and elemental geochemistry analysis. Confirmation of the origin and sedimentary environment of the mottled clay is not only of importance for redividing the Late Quaternary strata of the south China coastal area but also for reconstructing the paleoenvironment of the LGM in the coastal area of south China, or even the entire middle and low latitude regions.

2. Materials and methods

2.1. Characteristics of the studied drill cores

Samples were taken from three drill cores obtained from the PRD as follows: 1) The TS core was from the village of Tanshan in the Panyu District in the PRD (GPS: 23°0′14.16″N, 113°27′25.53″E) (Fig. 1B). Here, the mottled clay layer is sandwiched between Mid-Late Pleistocene (Q_3^2) marine mud and Holocene (Q_4) black coarse sand. The top of this drill core is modern cultivated soil with a thickness of 3 m (Fig. 2, Fig. 3A). 2) The JT core was from the village of Jiaotang of the Panyu District in the PRD (GPS: 23° 0′0.72″N, 113°29′58.51″E) (Fig. 1B). Here, the mottled clay layer lies between two marine deposits of high sea level periods (Fig. 2, Fig. 3B). 3) The SJ core was from the town of Sanjiao, Zhongshan City (GPS: 22°42′21.98″N, 113°28′38.66″E) (Fig. 1B). Here, both the underlying and overlying layers of the mottled clay are dark grey marine deposits. The ^{14}C age at the red dot in Fig. 3C is 9.5–9.3 ka, corresponding to the transition to the Holocene (Q_4). The mottled clay layers in these three drill cores exhibited close