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The genesis and paleoenvironmental records of Longji agricultural terraces, southern China: A pilot study of human–environment interaction

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ABSTRACT

Ancient agricultural terraces distributed over the mountainous areas in southern China can be taken as new objects for studies on human–environment interaction in the past. However, this type of study is rare. This study selected Longji Terraces (Longsheng, Guilin), one of the famous ancient agricultural terraces, to explore its genesis and paleoenvironmental records. Three soil profiles including an original hillslope woodland soil profile and two terrace profiles were sampled for analyses of physical and geochemical proxies and radiocarbon dating. Cultivated soil in the terrace profile shows aggradation, making the cultivated horizon a bottom–up chronological sedimentary sequence. Two basal samples in the cultivated horizons of two parallel terrace profiles show calibrated ages of 1361–1406 AD and 1335–1384 AD respectively, indicating that the genesis of Longji Terraces occurred during the late Yuan Dynasty in Chinese history. Strong survival pressure and desire for new living space in the turbulent social situation of the late Yuan Dynasty might have been the direct factor forcing some people of national minorities to migrate to the Longji Mountain area, where they effectively utilized the hillslope land and water resources for cultivation by building agricultural terraces and constructing a gravity irrigation network. Multi-proxy analyses of the cultivated horizon of one selected terrace profile reveal that human farming activity has experienced a staged strengthening process, including four stages since the late 14th century. Moreover, some changes of the intensity of human farming activity found within each stage might reflect the impact of climatic fluctuations on human farming activity during the Little Ice Age and the later warming period.

1. Introduction

As a topic in the forefront of scientific research in the international scientific community, global change has attracted extensive attention (Steffen et al., 2004). Earth's environmental evolution after the emergence of human activity occupies an important position in past global change, which is one of the major contents in global change research, and comprehensive study of human development history and environmental evolution of Earth has become one of the most important tasks in current scientific research (Dearing et al., 2006; Costanza et al., 2007; Hibbard et al., 2010; Newman et al., 2010). Because of the vast territory, diverse geomorphologic landscapes, various climatic conditions and geographical environment, and long history of human civilization, China has a wealth of materials about the changes of environment and human activity, including physical carriers of environmental evolution, historical data, and literature records. Therefore, China is always a favorable region for studies on human–environment interaction in historical periods. There are three famous ancient agricultural terraces distributed over the mountainous areas in southern China. Longji Terraces, which is located in Longsheng County of Guilin City in Guangxi Autonomous Region (Fig. 1), is one of the three famous ancient agricultural terraces, and the other two

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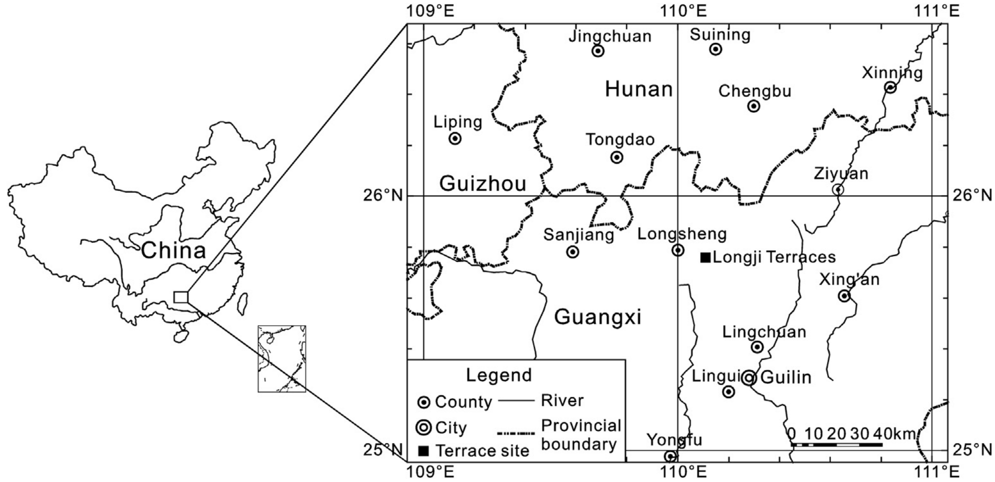

Fig. 1. Location map of Longji Terraces.

are Hani Terraces in Yunnan Province and Ziquejie Terraces in Hunan Province.

As a visible landscape feature in Longji Mountain area, Longji Terraces was constructed by people of national minorities in historical periods for habitation and crop farming. There are several inhabited villages with a sequence of agricultural terraces (Fig. 2A and B) in the Longji Terraces area. The agricultural terraces, which are commonly parallel to the contours of the hillslope and on slopes of about 26–35° (Cheng et al., 2002), consist of flat treads (cultivated areas), terrace walls (risers), and field ridges on the top of the risers (Fig. 2C). The terraces usually have considerable lengths along the contours. Terraces on gentle slopes normally have wider treads and shorter risers than terraces on steep slopes. The implementation of gravity irrigation (Fig. 2C) indispensably accompanies the conversion of original slope land into cultivable terraced field during the construction and use of the Longji Terraces. Irrigation water flows downwards from water sources in higher altitude areas through natural watercourses and anthropogenic channels or pipes, and

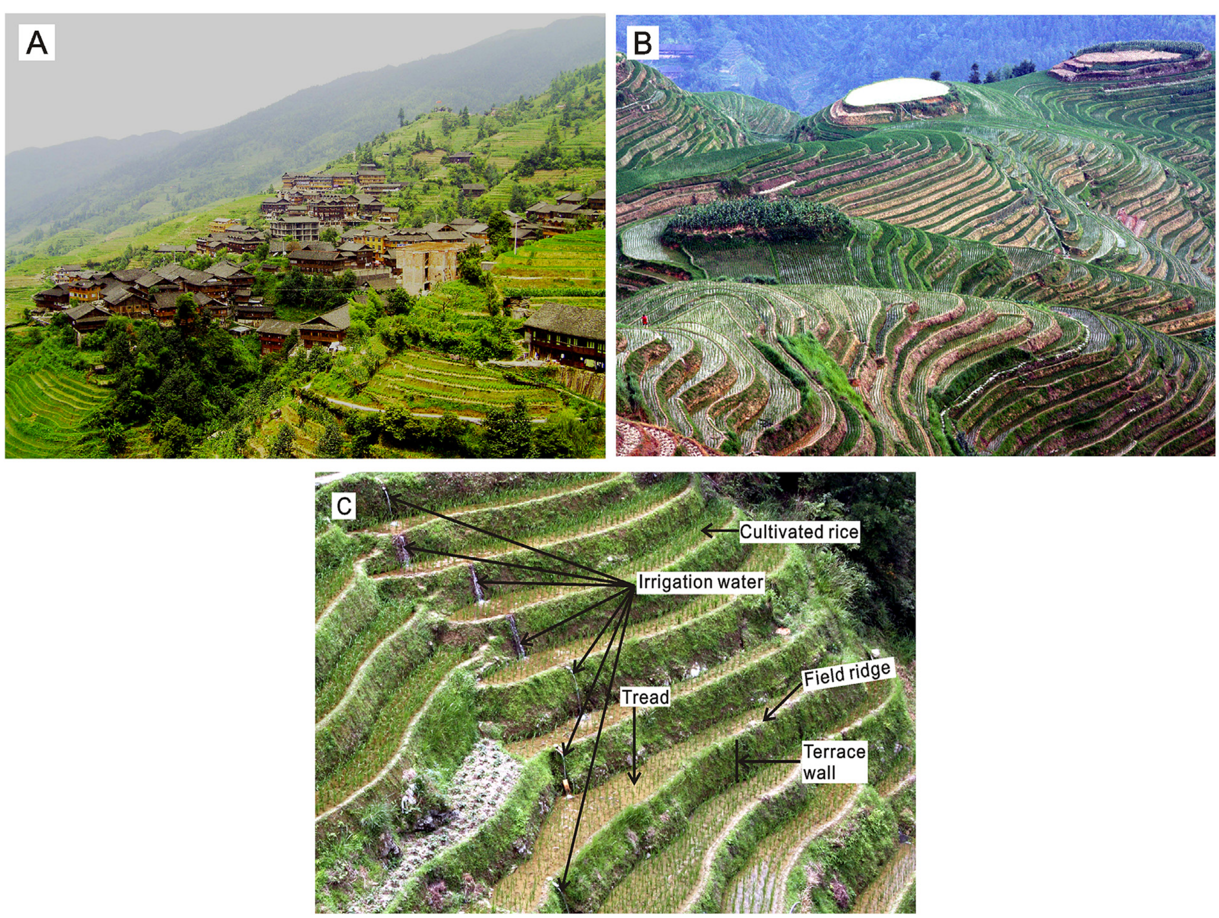

Fig. 2. (A) Ping'an village in Longji Terraces area; (B) agricultural terraces in Ping'an village; (C) gravity irrigation through Longji agricultural terraces.

then is used to irrigate the terrace land. The peasants maintain and heighten the field ridges in order to keep the terrace's function of water retention.

The ancient terraces present an ingenious way in utilizing the slope land and water resources in mountainous areas, and it is expected that abundant information about human–environment interaction in historical periods was recorded by the terraces. Several studies on the genesis or paleoenvironmental records of different types of terraces in the world have been reported. Branch et al. (2007) studied an abandoned prehistoric agricultural terrace in the southern Peruvian Andes through palaeopedological, sedimentological, archaeological, and palaeoecological approaches, and their results revealed two stages of terrace construction for *Zea mays* cultivation which were associated with two phases of landscape disturbance recorded in the adjacent mire basin archive. Henck et al. (2010) used an interdisciplinary approach to study the hillslope terraces (terracettes) in Jiuzhaigou National Park, northern Sichuan, achieved a greater understanding of the locations, formation, and persistence of the terracettes, and gained the radiocarbon and OSL dating evidence that reveal the long history of human habitation and the connection between terracette formation and human–land use interactions in their study area. The chronology of the development of the runoff terrace systems in the Petra region in Jordan was determined with OSL dating and radiocarbon dating by Beckers et al. (2013). The results suggest that the terraces were initially constructed around the beginning of the Common Era and the terrace agriculture lasted at least until 800 AD. Sediment analysis indicates a sudden sedimentological shift from underlying pebble layers to fine sediments in terrace fills associated with the terrace construction which made the erosion-dominated and unfavorable area cultivable. The initial era (647–778 AD) of the building of the broad irrigated terraces of Ricote (Murcia, Spain) as well as the construction progresses in the initial stages of terrace building within al-Andalus was revealed by Puy and Balbo (2013) with a combined approach of micromorphology examination, physico-chemical analyses, and radiocarbon dating.

Differing from most of the terraces described in other studies mentioned above, Longji Terraces and the other two ancient terraces in China are still in use for crop farming today. However, study on the evolution of human–environment interaction in historical periods in these Chinese ancient terraces is unknown. Three main aspects can be summarized from the limited reported research on ancient agricultural terraces in China. The first aspect refers to studies on the overall features of the ancient terraces which include the summary of the basic characteristics of the Ziquejie Terraces, Hani Terraces, and Longji Terraces (Tong, 2006), the investigation and speculation on the Hani Terraces' origination with an combined approach of historical records, ancient songs and survey data (Hou, 2007), and studies on the characteristics, background, stability and value of terrace landscape from perspectives of terrace agriculture, terrace culture, and terrace ecology (Jiao et al., 2002; Jiao et al., 2006; Yang, 2010; Hu and Shen, 2011). The second aspect focuses on the ancient terraces' specific elements such as terrace soil nutrients (Wen et al., 2009), water retention capacity, and infiltration characteristics of soils in the terrace area (Wang et al., 2012), rice varieties (Xu et al., 2010; Dong et al., 2013), and structure of water conservancy or hydrological features (Wang et al., 2007; Xu et al., 2011; Tan et al., 2012). The contents of the third aspect are the protection of ecological environment, ecotourism development, and sustainable development of the terrace landscape (Cheng et al., 2002; Huang, 2004; Gan et al., 2007; Gu et al., 2012).

This paper provides a pilot study on the information about human–environment interaction in historical periods in the Longji Terraces. Apart from the simple local record of the terrace formation history, there was no chronological method used to determine the age of the terrace genesis. Therefore, one of the aims of this study is to explore when the agricultural terraces started to be constructed using radiocarbon dating, and infer the relation between the terraces' genesis and its historical background. The other aim is to preliminarily understand the evolution of human farming activity and environmental changes in historical periods in this area based on physical and geochemical analyses and radiocarbon dating results of selected soil profiles.

2. Study area

The Longji Terraces in the Longji Mountain area is distributed over the margin of the Jiangnan ancient continent, west of Yuechengling Mountain. The Longji Mountain area with a maximum altitude of 1850 m and a minimum altitude of 300 m has an integrated geomorphologic landscape of high mountains, river terraces, and river valleys which developed under the impact of tectonic movements in geological periods (Cheng et al., 2002). Metamorphic rocks of Banxi Group, Upper Proterozoic Jixian System, which date back 800 million years, are the main parent rocks for the Longji Terraces (Tong, 2006). Mid-subtropical monsoon highland climate with four distinct seasons is prevalent in the Longji Terraces area. The annual average temperature and annual precipitation are 14.4–16.9 °C and 1600–1733 mm respectively (Cheng et al., 2002).

Ping'an village (Fig. 2A) inhabited by residents of Zhuang nationality, one of the several villages in the Longji Terraces area, was selected as the site for fieldwork and sampling. Ping'an village terraces (Fig. 2B) are representative and usually considered the core area of the Longji Terraces. There are more than 15,000 blocks of large or small agricultural terraces with a maximum altitude of 880 m, a minimum altitude of 380 m and an area of 4 km^2 in Ping'an village. Rice is the main food crop cultivated on the agricultural terraces.

3. Materials and methods

Three soil profiles, numbered LJTT-1, LJTT-2, and LJTT-3 in Ping'an village, were chosen to be the main locations of this study. These profiles were described referring to the USDA system of soil classification introduced by Xi (1994).

Profile LJTT-1 (25°45.5496′N, 110°6.8981′E; 880 m a.s.l.) is an original hillslope woodland soil profile (Fig. 3), northwest of the inhabited area. This profile comprises an Ah horizon (humus horizon), a Bw horizon (illuvial horizon), and a mixed horizon (B/C horizon) of illuvial horizon (B) and parent material horizon (C).

Profile LJTT-2 (25°45.4127′N, 110°6.8796′E; 822 m a.s.l.) is a terrace profile consisting of cultivated soil (Ap horizon) and original slope soil (Bw horizon and B/C horizon) (Fig. 3), southwest of the inhabited area. The terrace in which profile LJTT-2 is located was constructed in the modern period (about 1950s) according to a local peasant who is the owner of this terrace.

Profile LJTT-3 (25°45.4061′N, 110°6.99′E; 800 m a.s.l.) is a terrace profile including modern cultivated soil (Ap horizon) and buried cultivated soil (Abp1 horizon and Abp2 horizon) (Fig. 3). Bw, B/C and C horizons were identified in the original slope soil under the cultivated soil, but the bedrock was not reached (Fig. 3). This terrace where profile LJTT-3 is located was probably one of the terraces which were initially constructed because it is in the vicinity of the inhabited area, which might have been the priority area when peasants began to build terraces.

The cultivated horizon of profile LJTT-3 (46 cm thick) is much thicker than that of profile LJTT-2 (14 cm thick), which indicates that the cultivated horizon of profile LJTT-3 might have experienced an aggradation process during which the cultivated soil accumulated. It is inferred that the aggradation process occurred under two

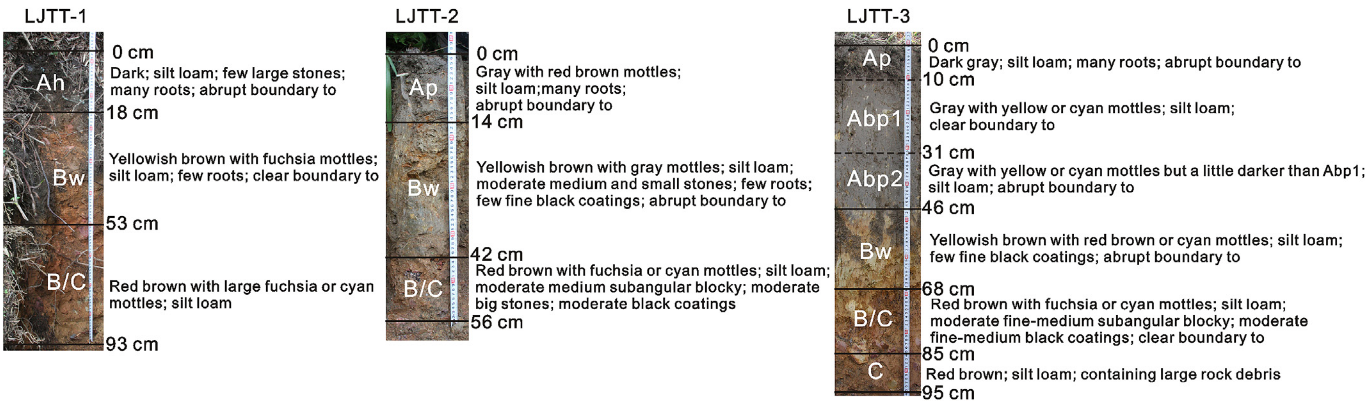

Fig. 3. Field description of the soil profiles in Ping'an village.

conditions. One is that the gravity irrigation brought sediments which were derived from the original slope soil and the cultivated soil of terraces above. The other is that the annual heightening of the field ridges ensured that the sediments could be preserved on the terrace land. In addition, the sediment source of this aggradation process might include a small amount of local aeolian sediments.

Three samples were taken from three horizons in profile LJTT-1, 28 samples were extracted at 2-cm vertical intervals in profile LJTT-2, and 70 samples were taken at 1-cm vertical intervals from 0 cm to 70 cm depth and another four successive samples were extracted according to the weathering degree from 70 cm to 85 cm depth in profile LJTT-3. In addition, one soil sample (LJTT-4-C) was extracted for dating from the bottom of the cultivated horizon in a profile (LJTT-4) which is close and similar to profile LJTT-3.

Bulk samples were analyzed for grain size, magnetic susceptibility, contents of inorganic geochemical elements, and organic geochemical elements in order to understand their characteristics of particle distribution, magnetism, element activity, and organic matter abundance. Grain size was measured with a Malvern Mastersizer 2000 laser granulometer (size range: 0.02–2000 μm). During the sample pretreatment, H_2O_2 and HCl were used to remove organic matter and carbonate respectively, and $(NaPO_3)_6$ was used to disperse aggregates.

Magnetic susceptibility of dried samples was measured on 8 cm^3 samples using a Bartington MS-2 magnetic susceptibility meter. Total organic carbon (TOC) content was determined by the method of potassium dichromate–sulfuric acid (oil bath) oxidation–ferrous sulfate titration (Bao et al., 2000, pp. 30–34). Total nitrogen (TN) content was determined by the method of potassium dichromate–sulfuric acid digestion–Kjeldahl (Bao et al., 2000, pp. 42–49); and total phosphorus (TP) content was determined by the method of perchloric acid–sulfuric acid dissolution–Mo–Sb colorimetry (Bao et al., 2000, pp. 71–76). Element geochemistry was performed using a Profile DV inductively coupled plasma atomic emission spectrometer (ICP-AES).

Five soil samples from different depths in the cultivated horizon of profile LJTT-3 and sample LJTT-4-C were submitted to the Accelerator Mass Spectrometry Laboratory of Peking University for AMS ^{14}C dating. Radiocarbon ages were calibrated using the OxCal V4.1.7 program (Bronk Ramsey, 2009) and the IntCal09 calibration curve (Reimer et al., 2009), and the calibrated ages were determined by weighted averaging of ages at 2σ precision.

4. Results

4.1. Radiocarbon dating results

Radiocarbon dating ages and calibrated calendar ages of samples from Ap, Abp1 and Abp2 horizons of profile LJTT-3 and sample LJTT-4-C are listed in Table 1. The bottom sample (LJTT-3-5-C) of the Abp2 horizon in profile LJTT-3 revealed a ^{14}C age of 545 ± 30 BP and a calibrated age of 1361–1406 AD which are close to the ages of sample LJTT-4-C, 575 ± 25 BP and 1335–1384 AD. Sample ages are older with depth in the cultivated horizon of profile LJTT-3.

Table 1
Radiocarbon dating results of soil samples from Longji Terraces.

Profile	Sample no.	Lab no.	Depth (cm)	Material	^{14}C age (yr BP)	Calibrated age (2σ) (yr AD)
LJTT-3	LJTT-3-1-C	BA101723	9–10	Organic matter	Modern carbon ± 25	
	LJTT-3-2-C	BA101724	18–19	Organic matter	25 ± 25	1846–1883
	LJTT-3-3-C	BA120408	28–29	Organic matter	430 ± 25	1428–1491
	LJTT-3-4-C	BA120409	32–33	Organic matter	440 ± 25	1422–1481
	LJTT-3-5-C	BA101721	44–45	Organic matter	545 ± 30	1361–1406
LJTT-4	LJTT-4-C	BA101722	45–46	Organic matter	575 ± 25	1335–1384

4.2. Results of physical and geochemical analyses

4.2.1. Grain size and magnetic susceptibility

Soil particles were classified as clay (<2 μm), silt (2–50 μm) and sand (>50 μm) according to the international common criteria for the classification of soil texture (Zhao et al., 1989). The φ value of grain size was calculated with the logarithm method (Krumbein, 1934) based on the Wentworth grain size scale (Wentworth, 1922) as follows:

$$\varphi = -\log_2^d$$

where d is particle diameter (mm). Grain size parameters such as mean particle size ($M\varphi$) and sorting coefficient (σ) were calculated using the graphical method (Folk and Ward, 1957). Results of grain size measurement reveal that the particle fractions of soils from three profiles show a relative percentage of silt (81.23–92.42%) > clay (5.62–12.74%) > sand (0.002–8.15%) (Fig. 4A–C). In profiles LJTT-2 and LJTT-3, the cultivated soil (Ap, Abp1 and Abp2 horizons) presents lower clay content, higher silt and sand contents, coarser mean particle size (lower $M\varphi$ value) and poorer sorting (higher sorting coefficient) than the underlying original slope soil (Bw, B/C and C horizons) (Fig. 4B and C). Clay content of soil from the humus horizon of profile LJTT-1 (10.21%) is higher than clay contents of the cultivated soil of profile LJTT-2 (5.62–7.88%) and profile LJTT-3 (7.15–8.69%) (Fig. 4A–C).

Magnetic susceptibility measurement results reveal that the low frequency mass-specific magnetic susceptibility (χ_{lf}) values of the cultivated soil of profile LJTT-2 and profile LJTT-3 are 3.65–5.26 $\times$ 10^{-8} m^3/kg and 3.50–4.77 $\times$ 10^{-8} m^3/kg, which are notably lower than those in the original slope soil of these two profiles (Fig. 4B and C). χ_{lf} value of soil from the humus horizon of profile LJTT-1 is 42.48 $\times$ 10^{-8} m^3/kg (Fig. 4A), much higher than χ_{lf} values of the cultivated soil of profile LJTT-2 and profile LJTT-3, and also higher than the χ_{lf} values of Bw horizon (15.14 $\times$ 10^{-8} m^3/kg) and B/C horizon (10.03 $\times$ 10^{-8} m^3/kg) of profile LJTT-1.

4.2.2. TOC, TN and TP and element contents

TOC, TN and TP contents of the cultivated soil in profile LJTT-2 were 14.16–32.26 g/kg, 1.41–3.21 g/kg and 0.37–0.54 g/kg

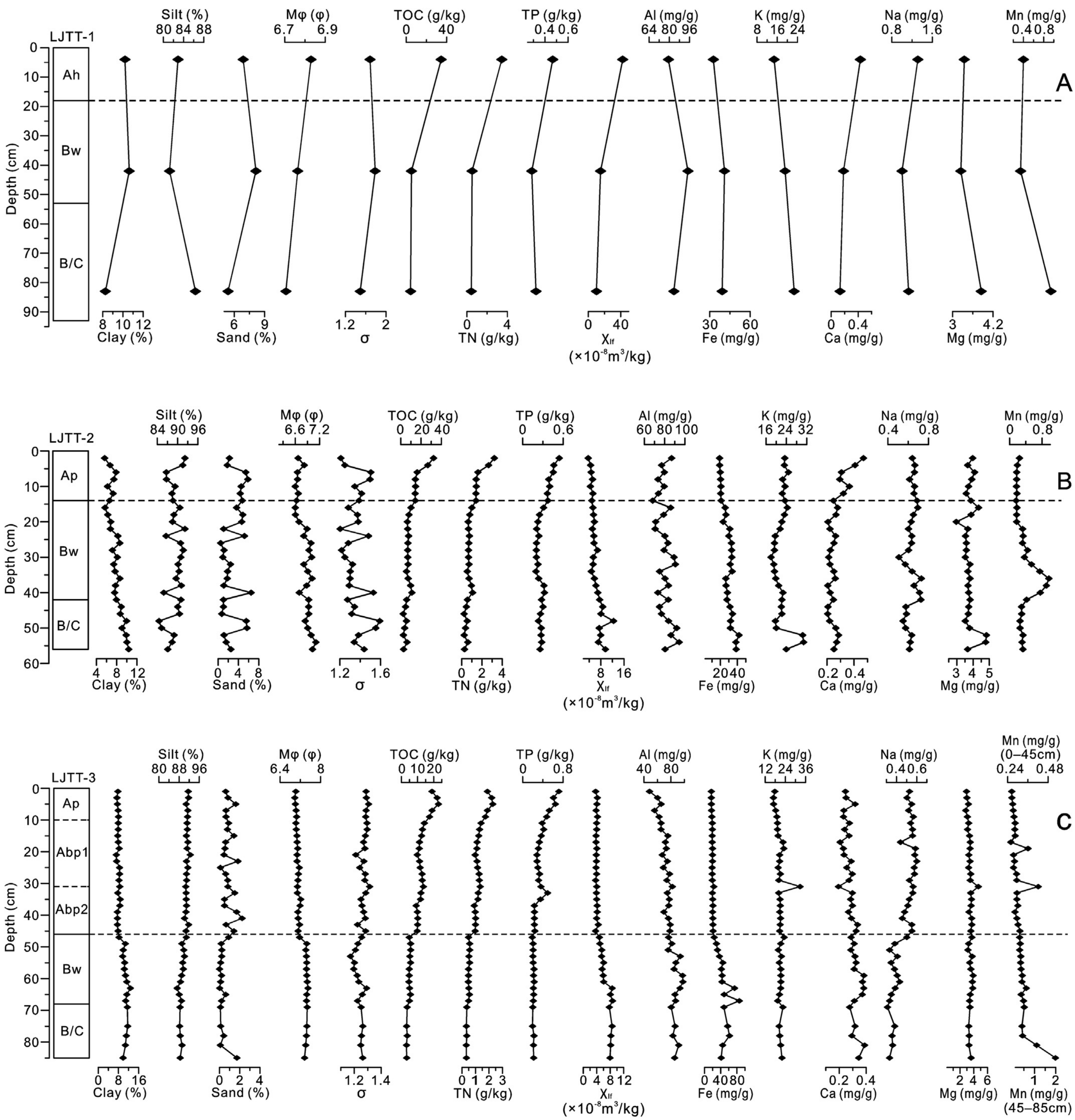

Fig. 4. Analysis results of grain size, magnetic susceptibility (χ_{lf}) and geochemical proxies of (A) profile LJTT-1, (B) profile LJTT-2, and (C) profile LJTT-3.

respectively, much higher than those of the original slope soil (2.37–10.96 g/kg, 0.24–1.08 g/kg and 0.20–0.32 g/kg) in profile LJTT-2 (Fig. 4B). In profile LJTT-3, the cultivated soil also shows higher TOC, TN and TP contents (9.14–22.94 g/kg, 0.91–2.28 g/kg and 0.23–0.72 g/kg) than the original slope soil (3.16–5.74 g/kg, 0.32–0.57 g/kg and 0.19–0.23 g/kg) (Fig. 4C). In comparison with the cultivated soil of profiles LJTT-2 and LJTT-3, the soil from the humus horizon of profile LJTT-1 displays higher TOC and TN contents determined to be 34.58 g/kg and 3.45 g/kg which are also greatly higher than the TOC and TN contents of the Bw horizon (5.16 g/kg and 0.51 g/kg) and B/C horizon (4.38 g/kg and 0.44 g/kg) of profile LJTT-1 (Fig. 4A).

Overall, Al, Fe and Mn contents in the Ah horizon of profile LJTT-1, Ap horizon of profile LJTT-2, Ap, Abp1 and Abp2 horizons of profile LJTT-3 are lower than those in the underlying horizons, and this phenomenon is especially prominent in profiles LJTT-2 and LJTT-3 (Fig. 4A–C). In profile LJTT-2, Al, Fe and Mn contents are 68.22–86.88 mg/g, 19.02–20.84 mg/g and 0.16–0.24 mg/g in the cultivated soil, and 70.55–94.35 mg/g, 23.25–42.03 mg/g and 0.17–0.97 mg/g in the original slope soil (Fig. 4B). In profile LJTT-3, Al, Fe and Mn contents in the cultivated soil are 48.30–82.12 mg/g, 16.84–22.86 mg/g and 0.26–0.42 mg/g, while those in the original slope soil show values of 75.99–97.86 mg/g, 23.88–86.00 mg/g and 0.30–1.98 mg/g (Fig. 4C).

K in the A horizons of profiles LJTT-1 and LJTT-3 suffered from leaching loss, but shows enrichment to a certain extent in the A horizon of profile LJTT-2 (Fig. 4A–C). Ca in the A horizons of profiles LJTT-1 and LJTT-2 displays enrichment, while Ca content in the A horizon of profile LJTT-3 is lower than that in the underlying horizons. Na in the A horizons of these three profiles experienced a process of enrichment to different degrees. Mg suffered from leaching loss to a certain extent in the A horizons of profiles LJTT-1 and LJTT-3 but shows enrichment in the A horizon of profile LJTT-2. The activities of alkali metal elements and alkaline earth metal elements in these three soil profiles are complex.

5. Discussion

5.1. Genesis of Longji Terraces

The positive correlation between the age and the depth showed in the dating results (Table 1) confirms the hypothesis that the cultivated horizon of profile LJTT-3 has experienced an aggradation process since its initial formation. Therefore, the bottom age of the cultivated horizon reveals when the cultivated soil initially developed.

The calibrated ages of paleosol sample LJTT-3-5-C (1361–1406 AD) and paleosol sample LJTT-4-C (1335–1384 AD) from profiles LJTT-3 and LJTT-4 (Table 1, Fig. 5A) which are two adjacent and parallel profiles with a similar thickness of the cultivated horizon reveal the initial formation age of the cultivated horizon on the terrace land. These ages correspond to the late period of the Yuan Dynasty in Chinese history (Fig. 5A), and it is believed that the genesis of Longji Terraces could date back to the late Yuan Dynasty. This conclusion is supported by the local record which indicates that the Longji Terraces was initially built in the Yuan Dynasty.

From the viewpoint of historical background, the late Yuan Dynasty was characterized by a deteriorating climate and turbulent social situation. The Yuan Dynasty experienced a rapid climate change period from the Medieval Warm Period (MWP) to the Little Ice Age (LIA) (Ge et al., 2002). In the late Yuan Dynasty, temperature in eastern China dropped significantly (Fig. 5B), which marked the beginning of LIA in eastern China (Ge et al., 2003). In addition, climate became dry in eastern China in the late Yuan Dynasty (Zheng et al., 2006; Yancheva et al., 2007; Zhang et al., 2008), especially in the northern region (Zheng et al., 2006; Ge et al., 2011, pp. 454–460; Tan et al., 2011). The Yuan Dynasty almost had the highest number of average annual natural disasters among the dynasties from the Qin Dynasty to the Republic of China (Ge et al., 2011, pp. 483–484). The climatic conditions which were very unfavorable for agricultural production were bound to bring serious negative impacts on human life in an agricultural society. Rice price index in the late Yuan Dynasty showed the highest value during the entire dynasty (Fig. 5C), indicative of food shortages for common people. The conflict between population and food shortage and the feudal rulers' corruption and cruel rule led to social unrest which was mainly characterized by the aggravation of the conflicts between different social classes and different ethnic groups, and frequent peasant uprisings and wars (Han et al., 2008). The number of wars in China peaked in the late Yuan Dynasty from the Northern Song Dynasty to the end of the Yuan Dynasty (Fig. 5C), which reflects a very turbulent social situation.

The decline of temperature in South China where Longji Terraces is located was not as notable as that in northern China. Climate during the late Yuan Dynasty in South China was relatively warm (Wang, 2007, pp. 27–28) but with a large fluctuation in moisture conditions (Zheng et al., 2006; Ge et al., 2011, pp. 454–460). The social situation in South China was probably not better than that in other regions. Rulers of the Yuan Dynasty divided the ethnic groups into distinct ranks with different identities and rights according to the order of surrender and political reliability (Xiao, 2007). People who had been living in Guangxi before being conquered, such as Han Chinese, people of Zhuang nationality, and Yao nationality, were classified into the lowest rank of "Nanren" (Han et al., 2008). National assimilation and integration were impossible to achieve because of the complex constitution of social ethnic groups, the political, economic, and cultural differences between different ethnic groups, and the unequal ethnic policies. Guangxi was the last region of the Southern Song Dynasty conquered by the Yuan Dynasty, and people in Guangxi put up a stubborn resistance during the defense process, so rulers of the Yuan Dynasty carried out tougher actions to strengthen their rule in Guangxi, especially in Guilin which was the ruling center (Zhong et al., 2008). In addition, the war between the Yuan Dynasty and Annam (Vietnam) aggravated the common people's burden in Guangxi (Zhong et al., 2008). All these situations resulted in a hard life for common people, intense social conflicts, and frequent civil revolts. Statistical data show that the number of wars in South China increased to 30 in the Yuan Dynasty, whose span is much shorter than the previous dynasties (Fig. 5D), indicative of frequent wars and instable social situations in South China during the Yuan Dynasty. Most of the wars were small-scale uprisings launched by the national minorities, and the number of inter-ethnic wars in Guangxi reached 37 during the Song and Yuan Dynasties (960–1368 AD) (Fig. 5E), accounting for 58.7% of the number of all the wars in South China during the Song and Yuan Dynasties.

Because of the limited scale and force, the uprisings launched by people of national minorities were not substantial threats to the Yuan Dynasty regime, but mainly aimed to fight for living space and resources. Large mountainous areas with small intermountain basins are distributed over the western, northern and eastern regions of Guilin, while the landforms in central and southern Guilin are mainly karst hills and valley plains. This provides a clue to understand the genesis of the Longji Terraces. Limited arable land, droughts, and floods became more and more serious factors affecting local people's life in the turbulent social situation. Then, some national minorities such as Zhuang and Yao moved to the Longji Mountain area to seek new living space because they were not in a dominant position when fighting for resources for survival in the plain regions. The people of national minorities transformed the original slope land into cultivable land by constructing

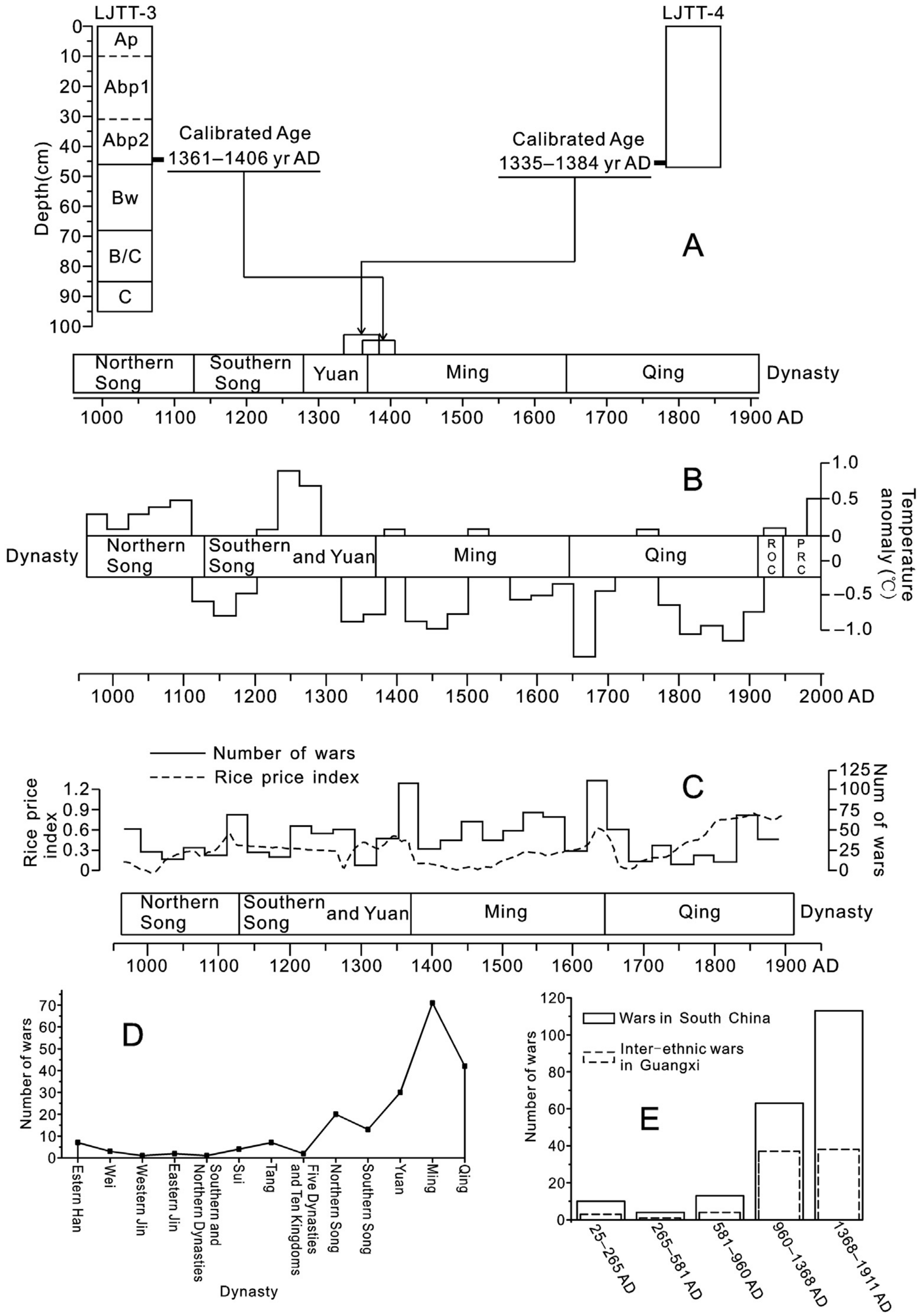

Fig. 5. (A) Dating ages of the bottom paleosols in the cultivated horizons of terrace profiles in Longji Terraces and their corresponding historical periods; (B) The winter half-year temperature anomaly (30-year resolution) in eastern China (east of 105°E, 25–40°N) since the Song Dynasty (after Ge et al., 2011, Appendix 4), ROC represents Republic of China, PRC represents the People's Republic of China; (C) The number of wars in every 30 years in China and standardized rice price index (30-year resolution) in the middle and lower reaches of the Yellow River since the Song Dynasty (after Ge et al., 2011, Appendix 4); (D) The number of wars in different dynasties in South China (data from Wang, 2007, pp. 35–39); (E) The number of wars in South China and inter-ethnic wars in Guangxi in different historical periods (data from Wang, 2007, pp. 35–39).

agricultural terraces. The water resources were effectively utilized to irrigate the terraces through a gravity irrigation system. Crop cultivation on terrace land reduced the impact of droughts and floods on agriculture and promoted the development of rice farming in mountainous areas. People living in this terraces area gained an isolated but relatively stable living environment without the intrusion of the external turbulent situation. The rise of the Longji Terraces reflected the innovation of farming mode and the development of agricultural civilization in the mountainous areas in southern China.

5.2. Environmental significance of physical and geochemical proxies

Results of physical and geochemical proxy analyses reveal some characteristics of the cultivated soil which are different from those of the original slope soil and the uncultivated woodland soil.

As rice is the main cultivated crop in the Longji Terraces area, the lower clay content of the cultivated soil might reflect the impact of hydroponic farming on the grain size distribution based on the fact that the cultivated soil has to remain waterlogged for a certain period during the process of rice cultivation. Eluviation during the hydroponic process could lead to the loss of clay (Li et al., 1992) resulting in the decrease of clay content and the relative increase of silt content. In addition, an unstable input of coarse particles into the cultivated soil could be brought by human farming activity. All these processes caused the cultivated soil to have increased mean particle size and particle mixing, resulting in coarser particles (lower φ value) and poorer sorting (higher sorting coefficient) than the original slope soil. Consequently, the evolution of farming activity could be inferred from the variation of grain size distribution in the cultivated soil. Coarser mean particle size (lower $M\varphi$ value) and poorer sorting (higher sorting coefficient) might indicate stronger human farming activity. Finer mean particle size (higher $M\varphi$ value) and better sorting (lower sorting coefficient) might suggest weaker human farming activity.

A study from Lü et al. (1994) revealed that an environment with high humidity is likely unfavorable for the accumulation and preservation of magnetic minerals. Ferromagnetic minerals with strong ferromagnetism (e.g., magnetite, maghemite) in the soil can change into ferromagnetic minerals with weak ferromagnetism during the process of reduction and decomposition under water-saturated conditions (Xing et al., 1988; Lu et al., 2012), which could explain the weakening of magnetism with a decrease of χ_{lf} in the cultivated soil. The higher χ_{lf} value in the humus horizon of profile LJTT-1 could be attributed to the absence of hydroponic cultivation during the process of surface soil formation on hillslope woodland. The phenomenon of low χ_{lf} values caused by the process of decomposition, transformation and leaching of ferromagnetic minerals under the condition of pseudogleyization was found in plinthitic red earth in southern China (Zhu et al., 2011). The variation of magnetic susceptibility value could indicate changes of moisture condition during the development process of the plinthitic red earth (Zhu et al., 2011). Therefore, it is inferred that the χ_{lf} values in the cultivated soil might be associated with the intensity of hydroponic farming activity. Lower χ_{lf} values and higher χ_{lf} values might correspond to stronger and weaker hydroponic farming activities respectively.

During the process of soil formation, accumulation of organic matter which was mainly derived from the crop residues led to higher TOC and TN contents in the cultivated soil. Much higher TOC and TN contents in the woodland surface soil result from the absence of crop cultivation and additional organic matter sources. TOC and TN contents could be associated with the intensity of human farming activity. Higher TOC and TN contents reflect enhanced accumulation of organic matter in the cultivated soil. Where TOC and TN contents show lower values, weaker human farming activity could be inferred. TP content is also related to the process of human farming activity, during which manuring could increase the phosphorus content.

The remarkable decrease of Fe and Mn contents in the cultivated soil was probably caused by the fact that some Fe and Mn with high valence were reduced into Fe and Mn with low valence, and then underwent the process of eluviation under the condition of hydroponic farming. The migration and loss of relatively stable Al also occurred in the cultivated soil, reflecting the effect of hydroponic farming. Therefore, lower Al, Fe and Mn contents might indicate stronger hydroponic farming activity, while higher Al, Fe and Mn contents might indicate weaker hydroponic farming activity.

5.3. Environmental records of profile LJTT-3

Using the proxies discussed above, the environmental records of the cultivated horizon of profile LJTT-3, with a long cultivation history, were explored. Three soil layers with some differences in macromorphology were distinguished in the cultivated horizon of profile LJTT-3 during fieldwork: modern cultivated soil (0–10 cm), and buried cultivated paleosols (10–31 cm, 31–46 cm). Changes of multi-proxy data near the boundaries between these three soil layers can be observed (Fig. 6). In addition, multi-proxy data show recognizable changes at the depth of 19 cm (Fig. 6), which suggests that layer 10–31 cm could be divided into two sub-layers, 10–19 cm and 19–31 cm. Therefore, it could be considered that the cultivated horizon of profile LJTT-3 has undergone four soil development stages including Stage A (46–31 cm), Stage B (31–19 cm), Stage C (19–10 cm) and Stage D (10–0 cm).

These four stages display a chronological staged strengthening process of human farming activity since the initial agricultural cultivation in the late 14th century, which is reflected by the general stepwise increase of TOC, TN and TP contents, and sorting coefficient with an order of Stage D > Stage C > Stage B > Stage A, and also reflected by the general stepwise decrease of the φ value of mean particle size (Fig. 6). In general, the χ_{lf} value and contents of Al, Fe, and Mn show gradual decline between these four stages (Fig. 6), which suggests a staged enhancement of hydroponic farming activity.

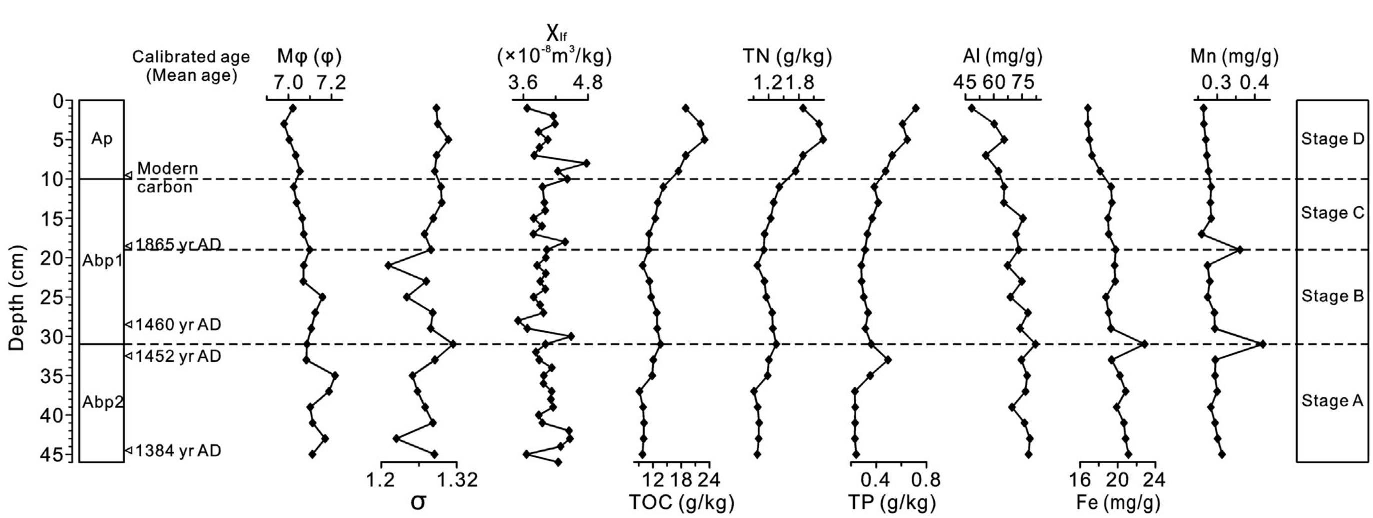

Fig. 6. Data of physical and geochemical proxies from the cultivated horizon of profile LJTT-3.

In the late period of Stage A, TOC, TN and TP contents increased significantly, and mean particle size and sorting feature become coarser and poorer respectively (Fig. 6), which reflects that human farming activity might be enhanced at the end of this stage. According to the dating results, Stage A appeared to be from the late 14th century to the late 15th century, when the climatic condition was similar to the modern climate (Ge et al., 2011, p. 506). Therefore, the enhanced human farming activity in the late period of this stage might suggest the rapid development of cultivation under a favorable climate.

TOC, TN and TP contents and sorting coefficient decrease from bottom to top within Stage B (Fig. 6), which might reveal a gradually weakening trend of human farming activity. This change of human farming activity from strong to weak in this stage might indicate deteriorating climatic conditions. The age of Stage B ranges between the late 15th century and the late 19th century. Ge et al. (2011, pp. 506–508) pointed out that South China began to enter the Little Ice Age with a cooling trend of climate after the 1480s. Therefore, the weakening trend of human farming activity within Stage B might be the response to the temperature decline in the Little Ice Age.

Conversely, TOC, TN and TP contents increase gradually from bottom to top within Stage C, and mean particle size and sorting become coarser and poorer (Fig. 6). These indicate that human farming activity was enhanced gradually during this stage, which probably suggests an improving trend of climate. Some previous studies have revealed that temperature began to rise significantly (Zhang, 1980; Wang et al., 1998) and moisture conditions were relatively favourable (Zheng et al., 2006) in South China from the 1860s which coincides with the initial mean calibrated age (1865 AD) of Stage C. Therefore, the enhancement of human farming activity during Stage C might have occurred under the background of climate warming after the LIA.

In Stage D, the modern farming period, TOC, TN and TP contents and sorting coefficients increased, and the φ value of mean particle size continued to decline (Fig. 6), possibly reflecting the further enhancement of human farming activity during the modern warming period. The declining χ_{lf} value and decreasing contents of Al, Fe and Mn within this stage (Fig. 6) seem to indicate the impact of modern enhanced hydroponic farming activity. The considerable increases of TOC, TN and TP contents in this stage might be related to the application of modern fertilizer. The enhancement of farming activity in Stage D is likely to be in relation to the effect of modern farming methods and the impact of developing the terrace landscape to a certain extent.

6. Conclusions

Information about human–environment interaction in historical periods recorded by the Longji Terraces, one of the famous ancient agricultural terraces in southern China, was preliminarily explored by this study using analyses of environmental proxies and radiocarbon dating. The calibrated ages of two lower paleosols in the cultivated horizons from two parallel terrace profiles were 1361–1406 AD and 1335–1384 AD, which reveals that the genesis of Longji Terraces could date to the late period of the Yuan Dynasty when the agricultural terraces were initially built for growing crops. The genesis of the Longji Terraces is inferred to be directly related to the turbulent social situation in the late Yuan Dynasty. Survival pressure forced some people of national minorities to migrate to the Longji Mountain area, where they made hillslope land cultivable by building terraces, and effectively utilized water resources through a gravity irrigation system. Deteriorating climate in most areas of eastern China in the late Yuan Dynasty, which was one of the important factors causing social unrest, played an indirect role in the genesis of the Longji Terraces. With the rise of the Longji Terraces, national minority people obtained a new stable place for living, farming was reformed, and development of agricultural civilization was promoted in this area.

The cultivated horizon of one terrace profile has experienced a process of aggradation since its initial formation and can be considered as a bottom–up chronological soil sequence according to its dating results. The gravity irrigation which brought sediments and the yearly heightening of terrace ridges provided the necessary conditions for this aggradation process. This cultivated horizon recorded a chronological staged strengthening process of human farming activity including four stages. Changes of farming activity intensity can also be found within each stage. Farming activity was enhanced in the late 15th century, but underwent a weakening process from the late 15th century to the late 19th century, which might reflect the negative impact of the deteriorating climate on crop farming during the Little Ice Age in this area. Human farming activity was enhanced in the late 19th century, which might suggest the warming trend of climate and indicate the termination of the Little Ice Age. The enhancement of human farming activity in modern farming period might reflect the response to modern warming climate as well as the impact of modern farming methods and the development of the terrace landscape.

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