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Possible relatedness between the outburst of the Diexi ancient dammed lake and ancient Chengdu's cultural change

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Abstract: The Diexi ancient dammed lake is in the upper reaches of the Minjiang River. Six terraces with lacustrine sediments occur at the base. These terraces are the products of the graded outburst of the Diexi ancient dammed lake. The outburst of the ancient dammed lake would certainly have had an impact on the Chengdu Plain in the lower reaches of the Minjiang River. In this paper, on-site sampling and laboratory analysis were used to analyze the sediments of the Diexi ancient dammed lake and the Jinsha site in Chengdu Plain, and the environmental indicators of each sediment layer were tested. Through a comparative analysis of the environmental indicators in the sediments at the two locations, the following results were obtained: the palaeoclimatic and palaeoenvironmental characteristics at the two locations generally show consistent changes. The most important finding is that the types and content of the major pollen taxa at the two locations are similar. The *Pinus* content strongly proves that the soil layers at the Jinsha site was sourced from the upper reaches of the Minjiang River. Considering that the demise of the ancient culture at the Jinsha site occurred close in time to the outburst of the ancient dammed lake, this similarity suggests that the cultural change at the Jinsha site may have been related to the outburst of the Diexi ancient dammed lake.

Keywords: Minjiang River; Diexi ancient dammed lake; Jinsha site; Palaeoclimate; Palaeoenvironment

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Introduction

Detailed, systematic studies have been conducted to obtain geological environmental information from the sediments of the Diexi ancient dammed lake in the Minjiang River (Wang et al. 2005; Wang et al. 2014), and a correlation has been observed between climate data from the sediments and seismic information. A study on the particle size distributions of the sediments of the Diexi dammed lake found that the sediments in the upstream section of the lacustrine sediments were mainly silty sand and sandy silt, while the sediments in the middle and downstream sections were finer, mainly clayey silt and silt (Xu et al. 2019). The high-resolution grain size distributions and magnetic susceptibility of the lacustrine sediments deposited during the last deglaciation period in the sedimentary profile in Diexi Xinmo Village in the upper reaches of the Minjiang River were analysed, and the observed pattern of a sudden increase and gradual decrease in grain size and magnetic susceptibility may indicate palaeoseismic events (Mao et al. 2011). In similar studies, the age of ancient flooding and abandonment of human sites has been demonstrated by examining the pollen, plant fossils and insect remains in the sediments of the Bronze Age site at the Yoxall Bridge in Stafford, UK (Smith et al. 2001). Ancient flood events recorded in the strata of four archaeological sites in the Colorado River canyon in Arizona, USA, between 1050 and 1170 years ago have been studied, and discussion about the impact of ancient flood events on the distribution of the archaeological sites of settlements and human activities has noted that early farmers chose settlement sites that reflected adaptation to ancient flood events (Anderson and Neff 2011). The distribution and accumulation conditions of the middle Holocene archaeological strata in the French Rhone River valley and natural sedimentary basin formation, including ancient flood sediments, have been studied systematically and comprehensively, and the archaeological cultural artefacts in this region were primarily distributed in the downstream alluvial plains and in the stratigraphic accumulations of alluvial fans from an alpine foothill river; on this basis, the ancient hydrology, flood events and secondary sedimentation effects on the distribution of archaeological sites in the Holocene basin were discussed (Jean-François 2011). The palaeoenvironmental context of the evolution of the Baodun culture on the Chengdu Plain, Sichuan Province, China, has been discussed (Huang et al. 2019). Zeng et al. (2016) attempted to demonstrate the linkage between the evolutionary history of the Baodun culture and palaeoclimate change by investigating subsistence strategies during the Baodun period, such as farming, tool use and food resources. Huang et al. (2010) identified a set of palaeoflood slackwater deposits interbedded in the Holocene loess-soil sequence within riverbank cliffs. Both the sedimentary criteria and the analytical results show that this sediment was sourced from a suspended sediment load associated with flooding. The timing of major flood events in the middle reaches of the Mississippi River over the past 1800 years has been determined by evaluating flood sediments from two floodplain lakes. The results show that the variation in the frequency of high-intensity flooding was regulated by the water supply in central North America and corresponded to the emergence and decline of a settlement on the Mississippi floodplain (Munoz et al. 2015). The discovery of an agricultural site from the Han Dynasty beneath 5-metre-deep flood sediments provides a vivid account of the cultural changes that resulted from a flood (Kidder et al. 2012). The three ancient soil layers in the Maoxian section of the Minjiang River have been exposed to the atmosphere at least three times, and these three ancient soil layers were probably caused by a dam-break event (Liu et al. 2018).

In summary, environmental archaeological research results documenting ancient flood events are of great scientific significance in revealing the nature of regional climatic and hydrological changes in response to global changes and clarifying the impact of major flood events on prehistoric cultural changes and social transitions. During modern and historical periods, flooding has largely been the result of regional heavy rains. However, in addition, rainfall-induced landslides have blocked rivers and formed lakes, and the failure of these dams can also cause river flooding, with peak flows that are often much greater than those of floods caused by rainfall. The outburst deposits in Diexi area can be divided into two periods: thick outburst deposits representing the largest early dam-break event and deposit terraces related to the subsequent smaller dam-break events (Ma et al. 2018). A comprehensive analysis of dam flood characteristics, distribution, and causes in China has been conducted (Liu et al. 2019). The outburst of the Tanggudong dammed lake in Sichuan in 1967 and the Yigongzangbo dammed lake in Tibet in 2000 both produced extraordinary flood peaks. In recent years, ancient dammed lakes have been identified along the Jinsha River, Brahmaputra River and other rivers in Southwest China (Chen and Cui 2015; Cui et al. 2009), indicating that large weir-like blockages are not uncommon in geological history. The Diexi ancient dammed lake is located in the upper reaches of the Minjiang River. A large number of large-scale collapses, landslides and debris flows occur in this area, and earthquakes occur frequently. This area is a typical fragile ecological environment. The Jinsha site is located on the Chengdu Plain. Studies have found that the Jinsha site suffered from ancient flood disasters (Jia et al. 2016; Lin 2006), but they did not further confirm the source of the ancient floods. The authors speculate that the demise of the Jinsha culture was probably related to the floods formed by the outburst of the Diexi ancient dammed lake. Therefore, the authors tested and analysed the environmental parameters, such as soil particle size, organic matter content, and sporopollen species and content in Diexi and Jinsha and then discussed the correlation between the outburst of the Diexi ancient dammed lake in the upper reaches of the Minjiang River and the change in ancient culture on the Chengdu Plain, which is important to revealing the impact of flood events on cultural change.

1 Study Area

The Diexi ancient dammed lake is located on the eastern edge of the Qinghai-Tibetan Plateau in the transition zone between the Qinghai-Tibetan Plateau and the western Sichuan Plain. The Diexi ancient dammed lake is surrounded by the Minshan Mountains to the north, the Longmen Mountains to the south and the Qionglai Mountains and other mountains to the east. The study area is also located in an area in which the depth of the Moho discontinuity varies, and its geological structure varies substantially. The crustal uplifts in the Songpan region are strongly correlated with fluvial erosion. The study area is also located in the middle of the famous "north-south seismic tectonic belt" in a triangle formed by the intersections of the NWW-oriented Songpan-ganzi syngeosynclinal fold belt to the east and west, the Qinling Mountains near the south of the EW syngeosynclinal fold belt and the NE-oriented Longmenshan fault belt. Consequently, this area exhibits strong seismic activity (Figure 1).

Six terraces with lake sediments at the base are located in the middle of the Diexi ancient dammed lake at Tuanjie Village (Figure 2a), showing that

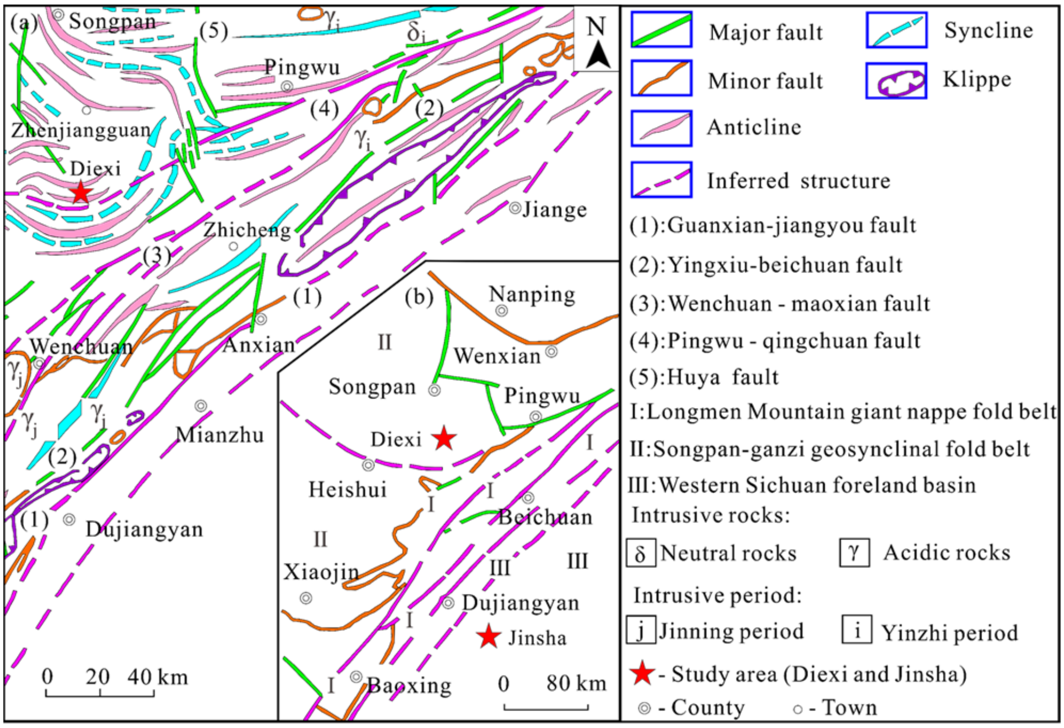

Figure 1 Geological structure map of the study area: (a) complex geological structure in Diexi area, (b) geographical location of Diexi and Jinsha (Wang 2009).

the outburst of the dammed lake was not a single event but rather occurred in a stepwise manner. The first outburst formed terrace VI, and the sixth outburst formed terrace I. The bases of these terraces are lacustrine sediments, and at the bottom of the terraces is a sand and gravel soil layer with clasts showing a directional imbrication arrangement. The upper portion is a flood-related silty clay layer, and the top is cultivated soil (Figure 2b). In total, there are six terraces, and they were formed by continuous erosional cutting caused by dam breaks, different from the formation process of ordinary valley terraces.

The sediments of the Diexi ancient dammed lake are a silty clay layer or silty sand layer. The sediments exposed at the ground surface exhibit clear layers, and patterns can be observed based on colour changes (Figure 2c). The patterns show a dark and light rhythm with approximately 50 rhythmic layers, which form a total thickness of 1 m. Each layer generally ranges from 2 to 5 cm in thickness, and oblique bedding can also be seen in

Figure 2 The Diexi ancient dammed lake terraces and the geological structure characteristics: (a) terraces developed on the sediments, (b) terrace structure, (c) horizontal striations in lacustrine sediments, (d) oblique bedding in lacustrine sediments, (e) flame structure, and (f) envelope structure.

the silty sand layer (Figure 2d). Disturbance phenomena, such as flame structures and envelope structures, also exist in these horizontal layers (Figures 2e and 2f). Figure 2e shows a flame structure on the slope section of Shawancun road in the upper reaches of Diexi. This type of flame-like structure exists in a single stratum. Various forms formed by the disturbance of fine layers can be seen in the layer, but the upper part features very flat horizontal bedding. Above and below the disturbed layer are horizontal layers. In the disturbed layer, the off-white deposits flow upward into the grey deposits, with an amplitude of approximately 0.5 m and a wavelength of 3~4 m. The off-white deposits between the troughs form large clumps. Figure 2f shows an envelope structure composed of yellow and light-grey sediment exposed in the Haizipo area. The disturbed sediments here show a state of entanglement, and the diameter of the structure is approximately 15 cm. The layer above this structure is a horizontal layer composed of yellow and grey sediment.

The Jinsha site is located on the Chengdu Plain (Figure 3), 5 km from the centre of Chengdu, and has an area of approximately 5 square kilometres. There are many rivers here. The Qingshui River is located 1.5 km south of the site, an old channel of the Pijiang River is located on the north side of the site, and the Modi River cuts across the middle of the site from west to east (Yao et al. 2005). The reasons why the outburst of the Diexi ancient dammed lake may have affected the Jinsha site are as follows: first, the Minjiang River originates from the Minshan Mountains and flows from the west side of the Chengdu Plain to the south. Across the entire Chengdu Plain, it is a suspended river above the groundwater level, and Dujiangyan is only 50 km away from Chengdu; however, the change in elevation of the Minjiang River actually reaches 273 m. The elevation of the Diexi ancient dammed lake is approximately 2500 m, while that of the Chengdu Plain is only 600 m. The flood following the outburst of the dammed lake likely posed a large threat to the Chengdu Plain. The second reason is the special geological structure of the Chengdu Plain. Because the Chengdu Plain is an inclined alluvial fan plain structure dipping in one direction, the flood oscillated back and forth across the fan-shaped plain, expanding the scope of the

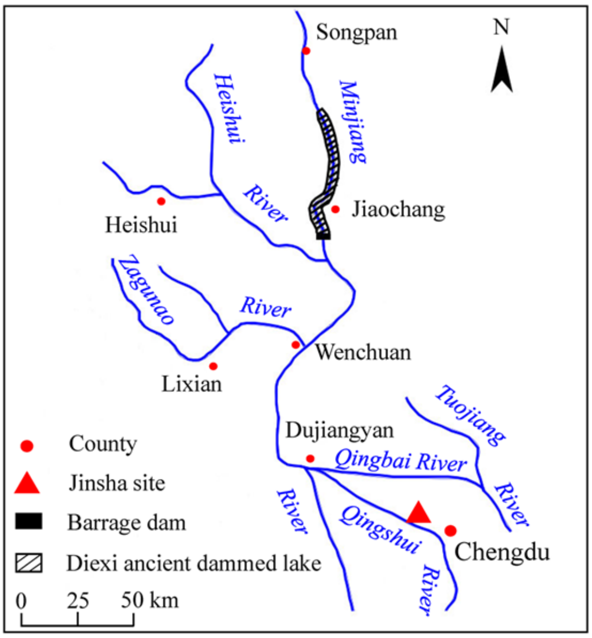

Figure 3 Geographical drainage relationship between the Jinsha site and the Diexi ancient dammed lake.

disaster. Jintangxia is the largest outlet of the Chengdu Plain, with high cliffs and a narrow river valley. Consequently, the Chengdu Plain experiences flooding due to poor drainage. The excavation of the Jinsha site revealed flood alluvium and tree trunks buried by silt (Jia et al. 2016). This evidence suggests that an unexpected and abnormal flood prompted ancient people to abandon the original site and migrate to higher land. The high-density resistivity method was used to confirm the existence of an ancient channel at the Jinsha site and determine the migration process of the ancient channel northward to the modern channel position (Yang et al. 2005). The authors thus speculate that the cultural change at the Jinsha site may have been related to the outburst of the Diexi ancient dammed lake.

In this paper, the environmental information extracted from the lacustrine sediments before the outburst of the Diexi ancient dammed lake and the cultural layers at the Jinsha site were compared and analysed to study the correlation between the outburst of the dammed lake and the cultural change at the Jinsha site.

2 Environmental Information Test

The formation and extinction of the ancient dammed lake in the upper reaches of the Minjiang River had a significant impact on both its lower reaches and the Chengdu Plain (Wang et al. 2020). The terraces are the product in different stages of the outburst. The material entrained by the outburst flood was moved downstream and deposited on the Chengdu Plain. Many types of environmental proxies exist. In sediments, particle size characteristics, organic matter content, and pollen type and content are closely related to the climatic environment during the deposition process. Therefore, using these three environmental proxies, this study compared the environmental characteristics of the alluvial sediments before the stepwise outburst of the Diexi ancient dammed lake with the soil environmental characteristics of the cultural layers at the Jinsha site and studied the relationship between Diexi and Jinsha.

2.1 Environmental information test and analysis of the Diexi ancient dammed lake

2.1.1 Soil particle size test

To a certain extent, particle size characteristics can reflect the relative magnitude of the water input, the strength of the hydrodynamic force, the change in precipitation in the lake area, and the pattern of dry and wet alternations in climate (Campbell 1998; Bianchi and McCave 1999; Peng et al. 2005). The six studied terraces are the products of six breaks in the dam of the ancient dammed lake; therefore, six soil samples were collected, using the lacustrine sediments above the terraces as the material corresponding to the period before the outburst. To facilitate the analysis, Ⅰ, Ⅱ, Ⅲ, Ⅳ, Ⅴ, and Ⅵ are used as the soil sample numbers. The test results based on the GBT 27845-2011 soil particle size analysis test method are shown in Figure 4a and b. The designations d_{60}, d_{50}, d_{30}, and d_{10} represent the particle sizes of the soil content smaller than the particle sizes accounting for 60%, 50%, 30%, and 10% of the total mass, respectively, and d_{50} refers specifically to the average particle size of the soil sample.

Figure 4a shows that the particle sizes of the sediments deposited before the first, second and third outbursts are similar and are all below 0.02 mm. The main particle sizes are relatively sticky, fine particles, indicating that the climate was relatively arid (the hydrodynamic conditions were weak, resulting in relatively thin deposits). The sediments deposited before the fourth and fifth outbursts have relatively large particle sizes and are mainly silt-sized particles, indicating that the climate was relatively humid (strong hydrodynamic conditions can create relatively thick deposits). In comparison, more coarse particles were deposited

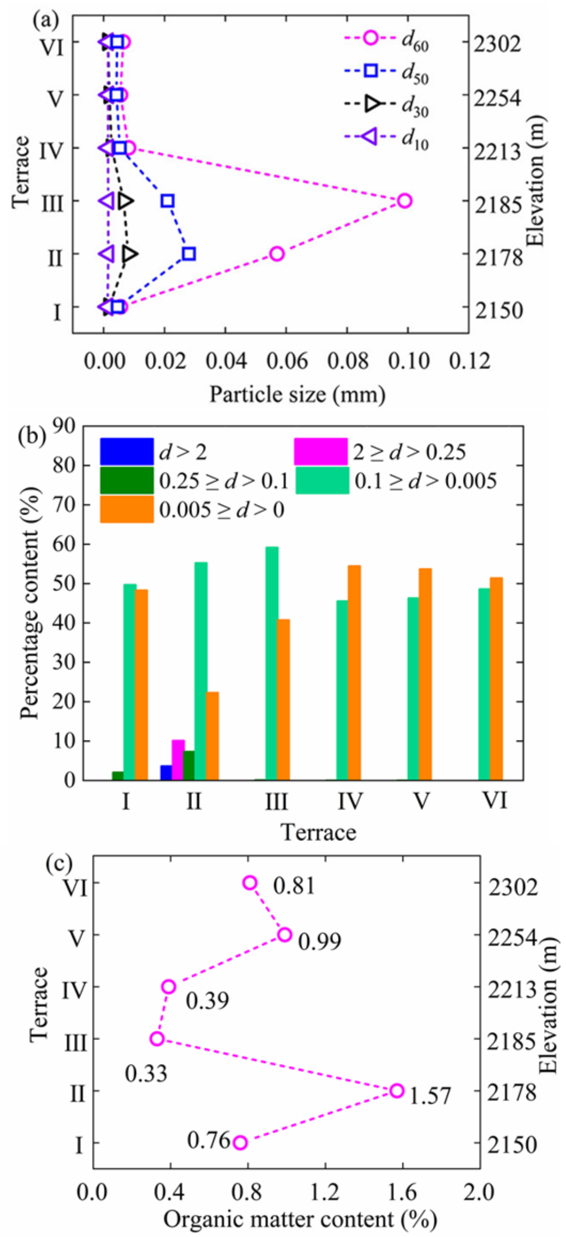

Figure 4 Results of the soil particle size and organic matter content tests for the terraces of the Diexi ancient dammed lake: (a) particle size, (b) size distribution, and (c) organic matter content.

before the fourth outburst (the d_{60} reached 0.1 mm), indicating the wettest conditions. The particle sizes of the sediments deposited before the last outburst correspond to silt, and some coarser particles were found, indicating that the climate was intermediate between relatively dry and relatively wet.

The particle size results of the lacustrine sediments deposited before the dam outbursts indicate that the average particle size exhibits a small-large-small pattern with lake level elevation. The average particle size of the lacustrine sediments reached its maximum before the fifth outburst. Overall, as the lake level elevation decreased, the clay content decreased, and the grain size of the lacustrine sediments increased before the sixth outburst. As the lake level elevation decreased, the climatic characteristics changed from relatively dry to relatively humid and then to relatively dry.

2.1.2 Organic matter content test

The organic matter content of a soil can reflect the climatic conditions and the process of biological soil formation during the period of soil formation. The organic matter content is typically expressed as the percentage of organic matter in dry soil. Typically, the higher the organic matter content was, the warmer the climate was during the soil formation period. Studies have shown that low levels of organic matter correspond to a cold climate. In contrast, when the climate is warm and humid, the natural vegetation is lush, and the organic matter content is relatively high (Müller and Mathesius 1999; Li et al. 2009; Cormie and Schwarcz 1994). Based on the soil organic matter determination method of GB 9834-1988, the organic matter content of the lacustrine sediments deposited before the outbursts from the ancient dammed lake are shown in Figure 4c, and the organic matter content range from 0.33% to 1.57%.

Based on the above data, the vegetation characteristics before the outburst of the dammed lake can be inferred: the environmental information from the sediments before the first outburst indicates that the vegetation was relatively lush. The vegetation before the second outburst was also relatively lush and flourishing. As indicated by the sediments before the third outburst, the vegetation was relatively sparse, and the lushness was significantly reduced. The vegetation before the fourth outburst was relatively sparse, with the least lush vegetation. The lushness was greatest before the fifth outburst. The vegetation before the sixth outburst was relatively sparse, and the lushness of the vegetation was lower than that in the previous stage. Based on the results of the organic matter content in the lacustrine sediments before each outburst from the dammed lake, the vegetation from high to low elevation exhibited a pattern of high-low-high-low, indicating a lush-sparse-lush-sparse process.

2.1.3 Pollen test

The type and content of spores and pollen can be treated as climate proxy. Among the natural factors used in the study of palaeoclimate, plants are the most sensitive to the living environment; thus, spore and pollen analysis is one of the more traditional and effective means for determining the vegetation status during the depositional period, and spore and pollen grains are readily preserved. The deposition time and climatic and environmental characteristics of the ancient dammed lake sediments in Diexi have been determined by pollen analysis (Wang and Wang 2013). The pollen assemblages in southern and eastern Fujian reflect an increase in deciduous broad-leaved components in the mid-subtropical mountain areas during the last glacial period, indicating a colder climate (Zheng and Li 2000; Yue et al. 2012).

The pollen samples collected from the sediments of the ancient dammed lake in Diexi were sent to the spore analysis laboratory at the State Key Laboratory of Earthquake Dynamics, Institute of Geology, China Earthquake Administration. The results based on the SY/T 5915-2000 palynological analysis method are shown in Figure 5. A total of 705 spore and pollen grains were counted in the six samples, with an average of 117 per sample. The sporopollen in the corresponding lacustrine sediments before the outburst of the Diexi ancient dammed lake can be divided into three types: arbour, shrub and grass, and fern and algae. In each sample, the arbour species had the highest pollen content, with an average of 85 grains and an average content of 71.3%. Among these species, *Pinus* was the most abundant, with an average of 64 grains, accounting for approximately 53.9%, followed by *Abies* (4.3%) and *Betula* (7.1%). *Quercus*, *Tsuga*, *Ulmus*,

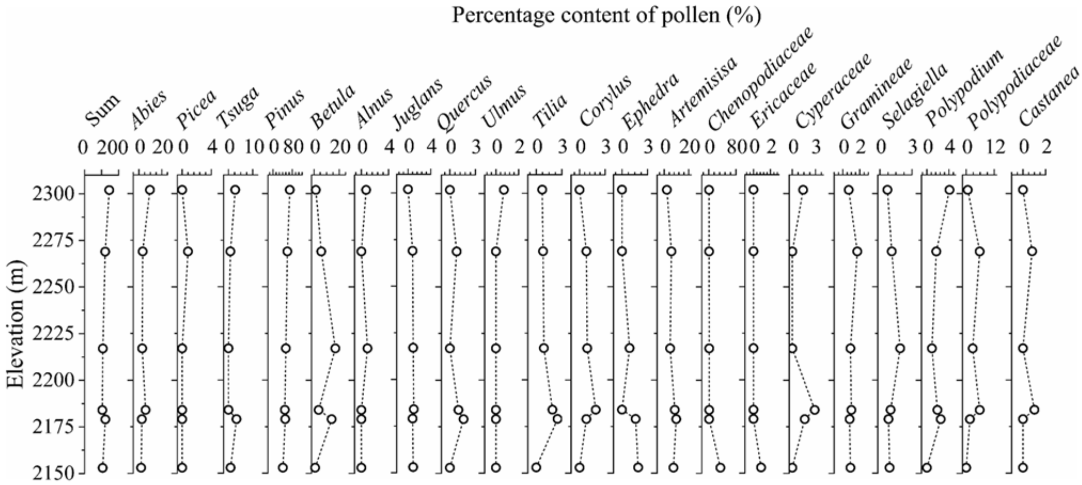

Figure 5 Pollen pattern in sediments of the Diexi ancient dammed lake.

Cultural layer	Thickness (cm)	Lithologic description	Age (a BP)
Ming Qing	7	Grey clay silt	582~38
Tang Song	16	Grey clay silt	1332~671
Han A	14	Grey-yellow clay silt	1795~1730
Han B	21	Grey-yellow clay silt	1925~1795
Han C	6	Grey-yellow clay silt	2091~1998
Han D	3	Yellow-grey clay silt	2152~2091
Shang A	8	Yellow-grey clay silt	3149~2996
Shang B	21	Yellow-grey clay silt	3567~3149

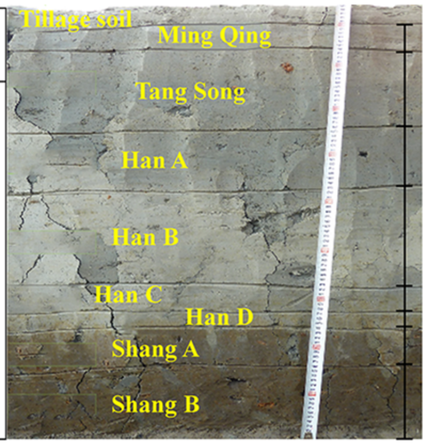

Figure 6 Cultural layers at the Jinsha site.

Juglans, *Tilia*, *Carya*, and *Cupressaceae* were present in small quantities or occurred sporadically in the samples. Shrubs and herbaceous plants contributed less pollen than the arbour species, with an average of 22 grains and an average content of 20.5%, with *Artemisia* (6.4%) and *Chenopodiaceae* (7.2%) being the most abundant. *Gramineae*, *Corylus*, *Hyperaceae*, *Ephedra*, and *Ericaceae* were present in small quantities or occurred sporadically. The content of fern spores and algae was relatively low, with an average of 9 grains and an average content of 8.2%, with *Polypodiaceae* being the most abundant, accounting for approximately 2.8%.

2.2 Test and analysis of environmental information in cultural layers at the Jinsha site

Archaeological staff at the Jinsha site have divided the soil layers according to the type of cultural relics, soil colour and soil quality, resulting in eight cultural layers at the Jinsha site (Figure 6). From top to bottom, the first layer represents the Ming Dynasty and Qing Dynasty, the second layer marks the Tang Dynasty and Song Dynasty, and the third to sixth layers are all Han Dynasty. Because of the different cultural times, the Han Dynasty soil layer is divided into four sections, and the seventh to eighth layers correspond to the Shang Dynasty. Existing research results have confirmed that the sediments in the profile at the Jinsha site are flood sediments (Wen et al. 2011; Jia et al. 2016).

2.2.1 Soil particle size test

The grain size analysis samples were taken from the excavation profile of the Jinsha site. Soil layers with cultivated soil were avoided during sampling to ensure that the samples contained no fresh plant rhizomes. The particle size test results are shown in Figure 7a and b. Figure 7a shows that each cultural layer is dominated by silt particles, with average particle sizes ranging from 0.008 mm to 0.014 mm. Generally, from bottom to top, the particle size of the sediments changes from fine to coarse to fine to coarse.

2.2.2 Organic matter content test

The test results for the organic matter content are shown in Figure 7c. The organic matter content ranges from 0.2% to 1.4%.

According to the soil organic matter content test results, the environmental vegetation profile can be obtained. The vegetation associated with the eighth layer (Shang B) was relatively lush compared with that of the entire profile; the vegetation associated with the seventh layer (Shang A) was relatively sparse and was less than that of the previous layer. The vegetation associated with the sixth layer (Han D) was relatively sparse but was slightly lusher than the previous layer. The vegetation associated with the fifth layer (Han C) appears to have been the sparsest, with the lowest lushness. The vegetation associated with the fourth layer (Han B) appears to have been relatively lusher than that of the previous layer. The vegetation associated with the third layer (Han A) appears to have been lusher still. The vegetation associated with the second layer (Tang Song) appears to have been relatively lush, with a lushness comparable to that of the third layer. Finally, the vegetation associated with the first layer (Ming Qing) appears to have been the lushest. From bottom to top, the vegetation environment changed from relatively lush to relatively sparse to relatively lush.

2.2.3 Pollen test

The results of the sporopollen tests at the Jinsha site are shown in Figure 8. A total of 1282 sporopollen grains were counted, with an average of 160 grains per sample.

The spores in the soil samples can be generally divided into three types: arbour, shrub and grass, and fern and algae spores. Woody plant pollen dominates the samples as a whole, with a high coniferous content. Common types include *Pinus*, *Tsuga*, *Picea*, *Abies*, *Cupressaceae*, etc. The broad-leaf pollen species were mainly *Quercus*, *Castanea*, *Betula*, *Ulmus*, and *Juglans*. The average pollen

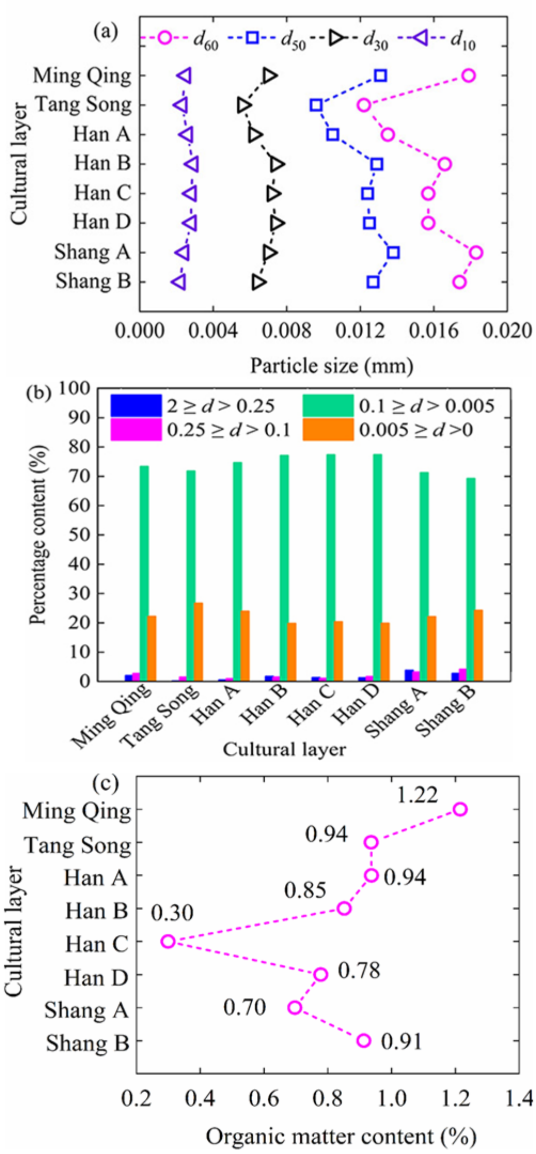

Figure 7 Results of the soil particle size and organic matter content tests in the cultural layers at the Jinsha site: (a) particle size, (b) size distribution, and (c) organic matter content.

content of arbour species in each sample was 107 grains, with an average content of 67.2%. *Pinus* accounted for an average of 69 grains (43.3%), followed by *Quercus* (8.3%), *Castanea* (3.6%), and small or sporadic amounts of other species in individual samples. *Betula*, *Juglans*, *Ulmus*, *Tsuga*, and *Abies* also appeared. The average pollen content of shrubs and herbs was 41 grains per sample, with an average content of 26.2%. The content of *Artemisia* (5.1%) and *Hyperaceae* (5.2%) were high, followed by *Corylus* (4.7%) and *Chenopodiaceae* (3.2%). *Ericaceae*, *Rosaceae*, *Ephedra*, and *Gramineae* also appeared

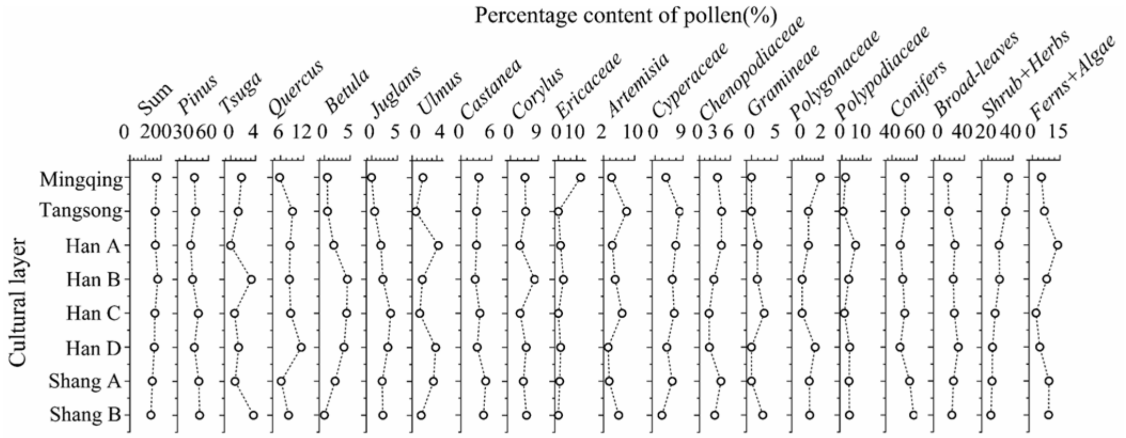

Figure 8 Pollen pattern in the cultural layers at the Jinsha site.

sporadically. The content of fern spores and algae were low, with an average of 10 grains per sample and an average content of 6.5%. The main fern and algae species include *Polypodiaceae* (3.1%), *Concentricystis* (0.9%), and *Pediastrum* (0.5%).

2.3 Comprehensive comparative analysis of the environmental information

The grain size characteristics of the lacustrine sediments before the outburst of the dammed lake and the soil from the cultural layers at the Jinsha site (Figure 9a) reveal that the average grain size at the two locations is from 0.0042 mm to 0.028 mm, implying fine-grained soil. The average grain sizes at the Jinsha site are generally similar and relatively uniform, whereas the differences in grain size are relatively large in the Diexi ancient dammed lake. This result occurs because the source of the sediments at the Jinsha site is the upper reaches of the Minjiang River, and the particle size is greatly affected by the river transport conditions. The sediments at the Jinsha site are plain sediments. Although this site is also affected by the source of the Minjiang River upstream, its geomorphological characteristics lead to small changes in sediment grain size. Comparison of the grain size trends at the two locations reveals a fine-coarse-fine trend.

The organic matter content characteristics (Figure 9b) show that the organic matter content at the two locations is from 0.3% to 1.6%, and most values are approximately 0.9%. The relative changes in the organic matter contents at the two locations are roughly the same, indicating that the

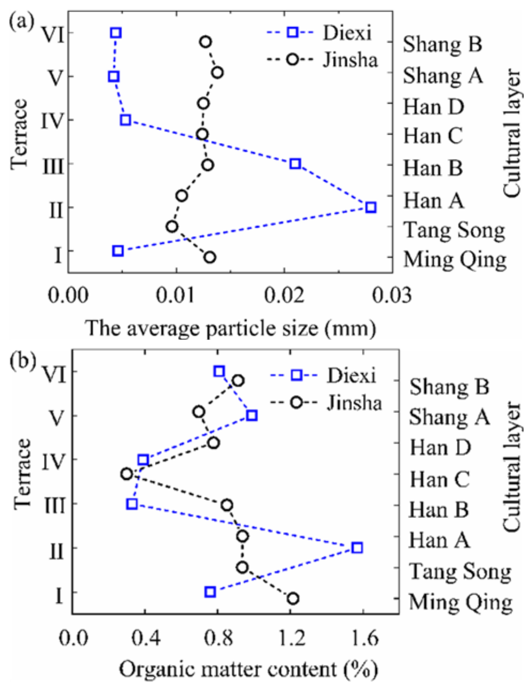

Figure 9 Comparison of the average particle size and organic matter content at Diexi and Jinsha: (a) average soil particle size, and (b) organic matter content.

vegetation lushness they represented was approximately the same. The vegetation characteristics represented by the soil organic matter content of the lacustrine sediments deposited before the outburst of the dam transitioned from relatively lush to relatively sparse to relatively lush with decreasing elevation (the sequence of the outburst). The vegetation characteristics represented by the soil organic matter content in the cultural layers at the Jinsha site also experienced a transition from relatively lush to relatively sparse to relatively lush with increasing elevation (progressive chronology). That is, the changes in vegetation characteristics represented by the lacustrine sediments before the outburst of the ancient dammed lake are roughly the same as those represented by the cultural layer sediments at the Jinsha site.

By comparing the types and content characteristics of spores and pollen at the two locations (Figure 10), we can see that the types of spores and pollen at the two locations are the same and that the main types of spores are also similar. First, the spore content is dominated by arbour species, which account for the majority, and *Pinus* pollen is the most abundant. Artificially cultivated vegetation is dominant in Chengdu; thus, for so many *Pinus* trees to have existed here is impossible. The most likely explanation is that the *Pinus* pollen came from the upper reaches of the Minjiang River. The difference in its content is due to the loss during the river transport process. Second, the pollen content of shrubs and herbs is lower than that of arbour species, and the pollen content of *Artemisia* is high. Third, ferns and algae have the lowest spore content, and most of them are *Polypodiaceae*.

3 Discussion

3.1 Some connection between Chengdu's cultural change and the outburst of the ancient dammed lake

The Diexi ancient dammed lake formed before 22 ka BP, and its extinction began at approximately 15~10 ka BP (Wang et al. 2005; Wang et al. 2007). The terrace ages of the Diexi ancient dammed lake are shown in Table 1. However, the carbon content in the lacustrine sediments of terraces I and II is very low, and the exact age cannot be measured.

According to the chronological framework of the ancient dammed lake terraces and the cultural layers of the Jinsha site, the age of terrace III is similar to that of the bottom layer of the cultural layers. A statistical analysis of the age of the Jinsha site was conducted, and the dating results of 13 samples were generally (4641±32)~(2857±32) a BP, with 11 samples yielding ages were (3623±32)~(2857±32) a BP (Wang 2015). According to the combined results of archaeological research and unearthed cultural relics, the Jinsha culture disappeared at approximately 3000 a BP (He and Lu 2017; Li et al. 2019), which is close to the period corresponding to the bottom layer at the Jinsha site, indicating that the demise of the Jinsha culture may have been related to the outburst of the ancient dammed lake. Although the chronological framework of the six terraces and the eight cultural layers do not correspond one to one, the comparative analysis of environmental information can confirm that the source of the cultural layers at the Jinsha site must have been the upper reaches of the Minjiang River because the average measured content of *Pinus* is 43.3% in the cultural layers, and such a large number of *Pinus* is unlikely to appear on the Chengdu Plain. The *Pinus* content represents definitive evidence that the source of the Jinsha cultural layers was the upper reaches of the Minjiang River, which is explained in further detail below.

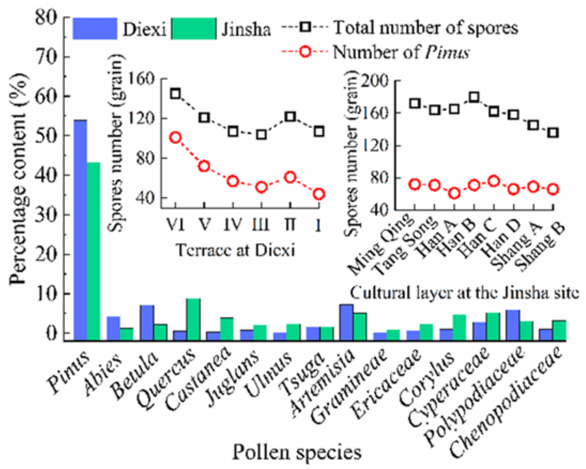

Figure 10 Comparison of the main pollen types and content at Diexi and Jinsha.

According to archaeological excavations, the Sanxingdui site on the Chengdu Plain was suddenly abandoned, and the trunks of trees at the Jinsha site were buried in mud and sand. Various signs indicate that the demise of the ancient culture on the Chengdu Plain was closely related to flooding. The ancient dammed lake on the Minjiang River

Table 1 AMS ^{14}C dating results for the ancient dammed lake terraces in Diexi

Terrace	I	II	III	IV	V	VI
AMS ^{14}C (a BP)	-	-	(3975±20)~(3428±82)	4880~(4741±72)	(8496±93)~(8255±93)	15000~10000

broke several times in the past 10,000 years and formed large floods, which may be related to the demise of the ancient culture (Wang et al. 2005). The main basis of this argument is as follows: (1) The Chengdu Plain has a special structure. The large flood rushed out of the Longmen Mountains. As the Chengdu Plain is an inclined alluvial fan plain structure dipping in one direction, the flood oscillated back and forth across the fan-shaped plain, expanding the scope of the disaster. In addition, Jintangxia, which has a towering cliff and a narrow river valley, is the largest outlet of the Chengdu Plain (Li and Liu 2012; Qiu 1999). The Chengdu Plain experiences flooding due to poor drainage. The 20~50 cm-thick water-rich silt layer of the eighth layer at the Sanxingdui site is strong evidence of flood stagnation (Lin 2001). (2) From the perspective of three environmental proxies, namely, particle size, organic matter content, and sporopollen, it is noted that the source of the sediment in the cultural layers at the Jinsha site has a high degree of consistency with the sediment of the ancient dammed lake terraces, and the environmental characteristics are also similar. Therefore, the change in ancient culture on the Chengdu Plain may be related to the ancient floods from the upper reaches of the Minjiang River. (3) Comparing the time series of the two places, the demise of Jinsha culture corresponds to the formation of terrace Ⅲ, indicating that the demise of the Jinsha culture may have been related to the ancient flood caused by the outburst of the Diexi ancient dammed lake.

3.2 Important evidence that the source of the Jinsha cultural layers was the upper reaches of the Minjiang River

The environmental information obtained from the Diexi and Jinsha site reveals a consistency in the provenance of the sediments. The content of *Pinus* in the cultural layers is as high as 43.3%. For so many *Pinus* to have existed locally is impossible. Thus, the *Pinus* is the most powerful evidence that the source of the Jinsha cultural layers was the upper reaches of the Minjiang River.

Four main *Pinus* species exist in Sichuan Province, including *Pinus tabulaeformis*, *Pinus massoniana*, *Pinus densata* and *Pinus yunnanensis*; the distributions are shown in Figure 11a. In combination with the distribution characteristics of the water system in Sichuan (Figure 11b), only the *Pinus* in the upper reaches of the Minjiang River can migrate to the Chengdu Plain, and *Pinus* is the main vegetation type in the upper reaches of the Minjiang River; thus, the *Pinus* content is relatively high. The Chengdu Plain has a long history of development and a high level of agricultural production. The reclamation index is one of the highest of the areas in Sichuan. Natural vegetation is rarely preserved. The vegetation types and distribution in Chengdu are shown in Figure 12. Cultivated vegetation is dominant in Chengdu; *Pinus*, belonging to coniferous forests, is distributed only in a small amount in areas west and east of Chengdu, and the *Pinus* content is relatively low in these areas. However, *Pinus*, with an average content of 43.3%, was detected in the Jinsha cultural layers. The most likely source was a large ancient flood from

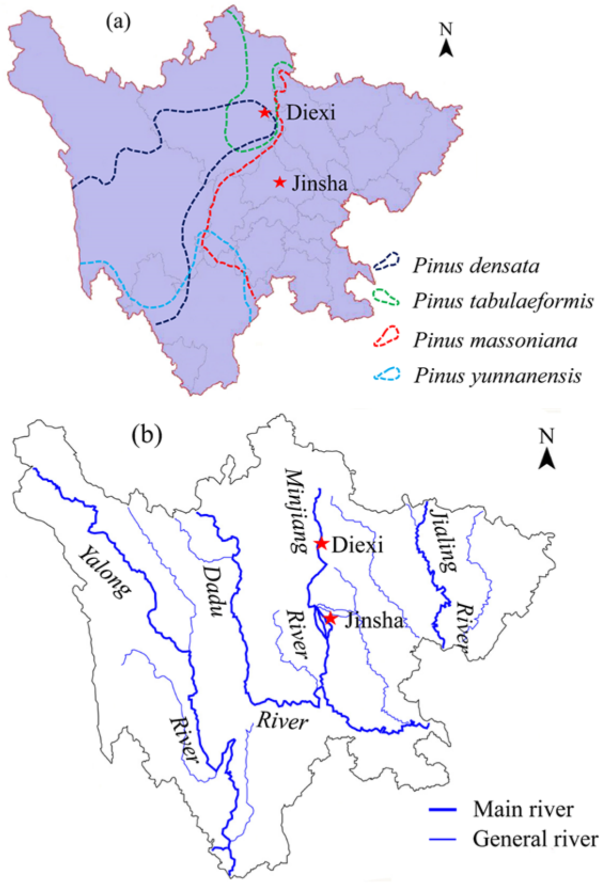

Figure 11 Distribution of *Pinus* types and main water systems in Sichuan: (a) *Pinus* distributions, and (b) main water systems.

the upper reaches of the Minjiang River. The formation of terrace III is close to the time at which the Jinsha culture disappeared. Furthermore, the outburst depth when terrace III was formed was as high as 30 metres, and such a large depth cannot be reached by ordinary floods, causing great harm to the Chengdu Plain. Therefore, we speculate that the demise of the Jinsha culture may have been related to the outburst of the Diexi ancient dammed lake.

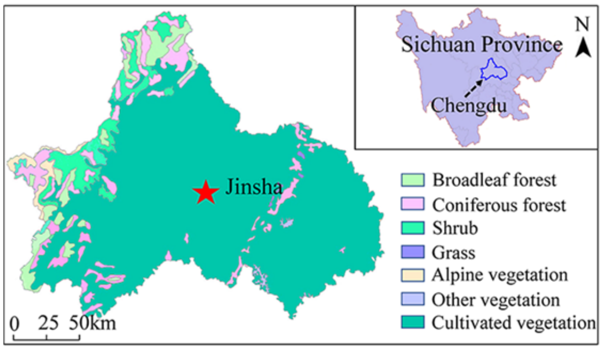

Figure 12 Main vegetation types and distributions in Chengdu.

3.3 Possible relatedness between the ancient dammed lake and the Jinsha site

The unearthed cultural relics at the Jinsha site indicate that human migration may have been related to emergencies occurring at the time. Sudden disasters in the Chengdu Plain mainly included ancient floods and earthquakes. The Jinsha site may have suffered from ancient flood disasters, as demonstrated using the environmental proxies preserved in the sediments at the Jinsha site (Jia et al. 2016). The interruption of the Ancient Shu Culture was due to a flood caused by the outburst of the Diexi ancient dammed lake, which was caused by an earthquake (Wen et al. 2013). However, the disappearance of the Sanxingdui and Jinsha civilizations was caused by a major earthquake in the Longmenshan fault zone (Lin and Wang 2017). According to the different viewpoints above and according to the environmental proxy indicators at Diexi and Jinsha, consistent trends (in sediment grain size, organic matter content, and sporopollen type and content) exist. These trends show that the source of the cultural layers at the Jinsha site was the upper reaches of the Minjiang River. The sporopollen results reveal that the Diexi ancient dammed lake and the Jinsha site have the same type of spores, and their relative contents are also similar. So many *Pinus* are unlikely to have been present on the Chengdu Plain. Thus, the source of the *Pinus* was the upper reaches of the Minjiang River. The bottom of the cultural layers has an age similar to that of terrace III, and the Jinsha culture disappeared during this period. Therefore, the cultural change at the Jinsha site may have been related to the large palaeo-flood caused by the outburst of the ancient dammed lake. According to the relative height differences of the terraces at various levels in the Diexi ancient dammed lake, the outburst depth of terrace III reached 30 m; this depth is much larger than ordinary floods caused by climate factors, indicating that the floods caused by the outburst of the dammed lake were very large. Therefore, the cultural change at the Jinsha site may have been related to the outburst of the Diexi ancient dammed lake. The Diexi area experienced at least ten palaeoearthquakes during the deposition of the sediments in the ancient dammed lake (Wang et al. 2014). Disturbances were also found in the sediments of the Diexi ancient dammed lake. The outbursts of the Diexi ancient dammed lake may have been caused by earthquakes.

However, the most importantly, we currently speculate that the disappearance of the Jinsha culture may be related to the outburst of the ancient Diexi dammed lake based on two factors: the consistency of provenance and timing. However, this evidence is not sufficient to show that the disappearance of the Jinsha culture was definitively related to the outburst of the dammed lake; it may have been related to some other floods. In other words, it is not a definitive conclusion that the disappearance of the Jinsha culture is related to the ancient dammed lake. In the future, we will continue to our exploration in order to find the more direct and effective evidence to prove the connection between the demise of the Jinsha culture and the Diexi ancient dammed lake. This work is important to revealing the impact of flood events on cultural change because the reason for the disappearance of the Jinsha culture remains a mystery.

4 Conclusion

From the analysis above, the following main conclusions can be drawn:

(1) The environmental proxies (grain size characteristics, organic matter content, and palynology) of the ancient dammed lake sediments and the soil in the cultural layers at the Jinsha site show consistent trends.

(2) The vegetation features represented by the lacustrine sediments before the outburst of the ancient dammed lake and the soil organic matter content of the cultural layers at the Jinsha site underwent a transition from relatively lush to relatively sparse to relatively lush. The characteristics of the vegetation changes are similar to those in the cultural layer soils at the Jinsha site.

(3) The types and content of spores and pollen in the soil of the cultural layers at the Jinsha site before the outburst of the Diexi ancient dammed lake are similar. The spores and pollen are mainly from arbour species, mainly *Pinus*, followed by shrubs and herbaceous plants, and fern and algae spores are the least represented.

(4) The palaeoenvironmental proxies of the pre-outburst lacustrine sediments of the ancient dammed lake and the cultural layers at the Jinsha site are consistent, indicating a consistent provenance. The *Pinus* strongly proves that the source of the cultural layers at the Jinsha site was the upper reaches of the Minjiang River. In addition, the age of the bottom layer of the Jinsha cultural layers is similar to the age of terrace III, indicating that a possible relatedness exists between the outburst of the Diexi ancient dammed lake at approximately 3.0 ka BP and Chengdu's cultural change.

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