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Phytolith analysis of Naminan archaeological site in Jinghong City, Yunnan Province

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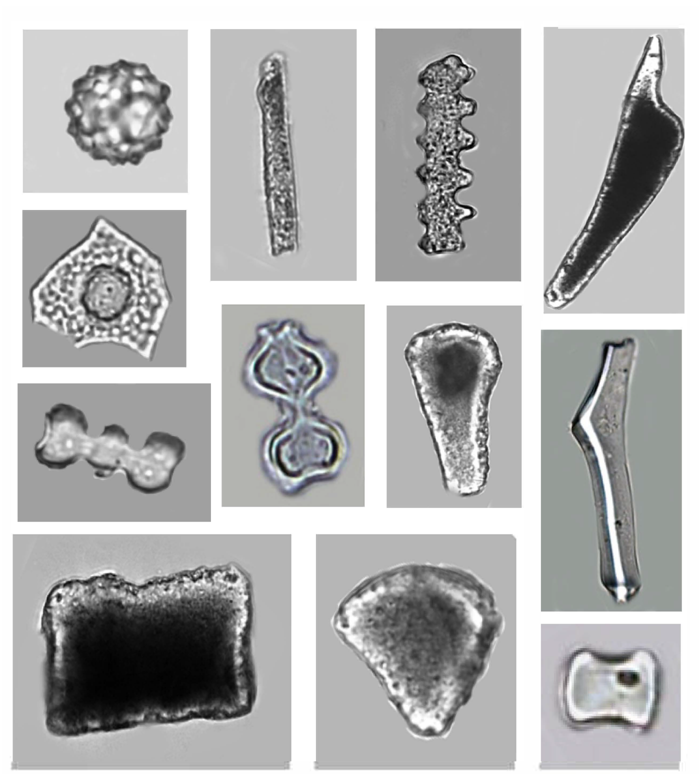
Graphical abstract



Plant microfossil phytolith from archaeological site in Yunnan reveals local climate change more than 10000 years ago.

Public summary

■ A Paleolithic-Neolithic archaeological site (Naminan) in Yunnan Province is studied in this research.

■ Phytolith record at Nanminan site are used to reconstructed the climatic conditions.

■ Naminan experienced a sequence of warming followed by cooling followed warming.

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Abstract: The global climate underwent tremendous changes during the transition from the Last Glacial Period to the Holocene. At almost the same time, human society transitioned from the Paleolithic to the Neolithic. Therefore, the relationship between climate change and human activity during this period has become a research hotspot. Yunnan Province is a region with a great abundance of Paleolithic archaeological sites in China; however, Neolithic sites are relatively few. There has also been relatively little research on paleoclimatic conditions during the Paleolithic-Neolithic transition in Yunnan. Phytoliths, as a highly durable and long-lasting form of plant microfossils, can be an important means for reconstructing paleoclimates. In this study, we examined the Naminan site in Jinghong, which was occupied during the transitional period from the Paleolithic to Neolithic. Based on our analysis of the phytolith record at Naminan, we reconstructed the climatic conditions for each of the archaeological strata and discussed possible human activities. The results show that Naminan experienced a sequence of warming followed by cooling and warming, which is consistent with previous paleoclimate research in other areas of Yunnan Province.

Keywords: Yunnan Province; phytolith; Paleolithic-Neolithic transition; paleoclimate; human activities

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1 Introduction

A suitable climate is the basis for human survival and cultural development, and both human evolution and the development of civilization are closely related to climate change[1,2]. During the Last Glacial Period, the mean global temperature was relatively low[3], and there were several abrupt climate change events, after which the Earth entered warmer conditions of the Holocene. The end of the Last Glacial Period and the beginning of the Holocene coincided with the transitional period from the late Paleolithic to early Neolithic[4]. Therefore, the development of human civilization during this period was probably closely related to climate change, which has long been a focus of research.

Yunnan Province is located in Southwest China. Influenced by the Indian Ocean monsoon and its special topography, most of the Yunnan Province is characterized by warm winters, cool summers, and relatively verdant conditions throughout the year[5]. During the Last Glacial Period, Yunnan was less influenced by global cooling trends than most other areas of China, making it more suitable for human habitation[6]. Many Paleolithic sites and ancient human fossils in China, such as the Jianchuan-Xiangbi Cave Site, Fuyuan-Dahe Site, and Jiangchuan-Gantangqing Site, have been discovered in this area. However, in the context of warmer Holocene conditions, there are fewer Neolithic sites in Yunnan, and the cultural characteristics of the archaeological remains seem to have lagged behind those described in Central China[7]. The study of climate change during the Paleolithic-Neolithic transition period in this area is of great significance to our understanding of the development of ancient human ways of life and civilization in the region.

Plant communities respond significantly to climate change, and different sets of climatic conditions correspond to different vegetation communities. Therefore, there is a strong basis for reconstructing paleoclimatic changes using both macro- and microscopic plant remains. Phytoliths are a major type of plant microfossils derived from the cells of plant families, including Poaceae, Cyperaceae, and Asteraceae. Phytolith morphology is, to some degree, related to plant species [8]. Phytoliths are often deposited in situ and can be preserved for a very long period following the death of a plant. Phytolith deposition may be related to ancient human activities, and phytoliths can be deposited in large quantities at sites and in their surrounding environments. The relationship between humans and plants can be studied by collecting relevant sediments and extracting phytoliths for species identification and statistical analysis. For example, phytoliths from the genus *Oryza* provide important evidence concerning the origin of early agriculture [9]. Previous studies have also found that morphological characteristics of phytoliths are related to climate change. For example, BULLIFORM FLABELLATE, BILOBATE, and BLOCKY (rectangular) phytoliths indicate warm climatic conditions, whereas elongated, ACUTE BULBOSUS, CRENATE, and RONDEL phytoliths indicate a cold climate [10,11]. Several domestic and foreign studies have used either phytoliths occurring in natural sediments or sediments from archeological sites to model sequences of climate change, and this approach has achieved remarkable results [12−15]. In some areas of Yunnan, phytolith analysis has been used to analyze archaeological sites since the Neolithic[16,17]. However, there are no examples of phytolith analyses being conducted for paleolithic archaeological sites in Yunnan; thus, further research is warranted.

Located in Jinghong, Naminan is a rare archeological site in Yunnan that spans both the Paleolithic and Neolithic periods [18]. Researchers have excavated a large number of animal and plant remains, as well as various cultural artifacts, which have provided important information for the reconstruction of human lifeways, environmental conditions, and human-environmental relationships during the Middle and Upper Paleolithic and Early Neolithic in Southwest China. This study aimed to reconstruct the climate change model, compare it with other archaeological sites and natural stratigraphic environment studies in Yunnan, and provide a basis for discussing vegetation changes and ancient human activities in this area.

2 Materials and methods

2.1 Materials

Naminan Cave is located in the west of the Luoguo Mountains, north of Bala Village, Jinghani Township, Jinghong City, Yunnan Province. It is the third cave distributed from north to south at the base of the fault cliff (Fig. 1). The coordinates of the cave entrance are 21°43′09.7″N, 100°55′24.4″E, 756 m a.s.l.. Measured at the top layer of sediments, the northeast length is 16.4 m, the southwest width is 14.1 m, and the distance from the top of the cave to the stacked layer is 17.9 m. The interior of the cave covers an area of approximately 300 m^2.

The cave deposits are mainly dry silt and contain calcrete nodules. According to the changes in artifact types and soil color, the sequence can be divided into six layers from top to bottom, with a disturbed layer on the surface and five cultural layers below. The upper set of cultural layers (Layers II, III, and IV) is loose, and the lower set of cultural layers (Layers V and VI) is dense, so there is a significant unconformity between the upper and lower layers. In general, the upper and lower cultural layers show consistency but differ slightly in terms of their cultural appearance, indicating that they belong to the same cultural system.

Fig. 1. The outside view of the Naminan site.

The experimental samples were collected from the Naminan cave between April 25, 2013, and May 6, 2013. The total thickness of the sediment deposit was 4.66 m, including six main layers (①-⑥ in Fig. 2; in this study, I-VI is used instead); 233 samples for phytolith analysis were collected from the profile at 2 cm intervals. Several topsoil samples were randomly collected from the Luoguo Mountains surrounding Naminan for modern comparative collection.

2.2 Methods

Four samples of animal bones, spiral shells, and ceramic sherds were collected from archaeological sediments at Naminan and sent for dating to the China Seismological Bureau and the Laboratory of Archaeology and Cultural Relics Protection, School of Archaeology and Museology, Peking University. Phytoliths were extracted using the heavy liquid separation method [19], and impurities were removed by sieving. The specific steps are as follows:

(i) Three grams of each sample was added to a 250 mL beaker.

(ii) HCL (10%) was added to the 250 mL beaker until there were no bubbles; water was added and the solution was stirred well.

(iii) The supernatant liquid was poured out and the material was retained at the bottom; water was added to the tick mark of the 250 mL beaker.

(iv) The samples were filtered through a sieve with a 250 μm aperture, transferred to 10 mL centrifuge tubes, and centrifuged at 3000 r/min for 1 min. The supernatant liquid was discarded.

(v) Equal volumes of a mixed solution of 10% NaOH and 10% $Na_4P_2O_7$ were added to the centrifuge tube, and the supernatant liquid was discarded after the centrifugation.

(vi) Saturated HNO_3 (6 mL) was added to each sample and heated in a water bath for 30 min.

(vii) Samples were dried and dehydrated; heavy liquid with a specific density of 2.3 was added and mixed evenly.

(viii) Centrifugation was done for 1 min at 3000 r/min and

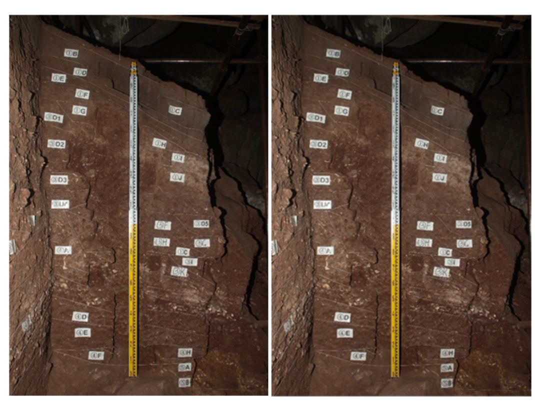

Fig. 2. Stratigraphic sequence of the Naminan site.

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the suspended solids were extracted.

(ix) Suspended solids were transferred into 10 mL centrifuge tubes, washed with water, and centrifuged three times.

(x) Samples were filtered through a sieve with an aperture of 7 μm, and the small particle impurities were discarded.

(xi) The material on the bottom was transferred into 1.5 mL centrifuge tubes and the supernatant liquid was separated by centrifugation.

(xii) Sample slices were made with neutral balsam.

The extracted samples were analyzed and phytoliths were counted under a microscope (model, Olympus CX 23). The number of different phytolith morphologies was recorded. At least 500 phytoliths were counted for each sample, and a total of 50 samples were analyzed. The phytolith types were described according to the Phytolith Nomenclature (ICPN) 2.0 [20].

3 Results

3.1 Chronological results

According to the dating results from 2000, the age of the Naminan site ranges between ～23 ka B.P. and ～10 ka B.P. (Table 1), which is equivalent to the late Paleolithic age. This is consistent with the cultural characteristics of the unearthed objects, which confirms the reliability of the results.

3.2 Results for phytolith from the topsoil samples

There are many types of phytoliths in the topsoil of the Luoguo Mountains. The most common types are ACUTE BULBOSUS (12.1%), ELONGATE ENTIRE (16.9%), BLOCKY (square) (14.0%), BLOCKY (rectangular) (16.3%), and BULLIFORM FLABELLATE (21.3%) (Fig. 3).

According to previous studies, the climatic characteristics reflected by these various forms of phytoliths are as follows [15, 21,22]: BULLIFORM FLABELLATE, BLOCKY (square), BLOCKY (rectangular), BILOBATE, SADDLE (long), and SADDLE (short) indicate warm climate; ACUTE BULBOSUS, ELONGATE ENTIRE, ELONGATE DENTATE, CRENATE, spheroid, RONDEL, and POLYLOBATE indicate cold climate; BLOCKY (square), BLOCKY (rectangular), BULLIFORM FLABELLATE, BILOBATE, and SADDLE (long) morphologies for Pteridophytes and Cyperaceae indicate humid climate; ACUTE BULBOSUS and SADDLE (short) morphologies for these species indicate a dry climate; other types, such as woody plant and palm phytoliths (globular echinate), are not very distinctive in terms of their association with climatic type.

In the modern topsoil samples, the proportions of BULLIFORM FLABELLATE, BLOCKY (square), and BLOCKY (rectangular) phytoliths, which represent a humid climate, were significantly greater than the proportions of those representing a cold climate. However, the proportions of ACUTE BULBOSUS and ELONGATE ENTIRE phytoliths, which represent a dry climate, were similar to the proportions of phytoliths representing a humid climate. The phytolith morphology in the topsoil represented the characteristics of a mild and humid climate, which is consistent with modern local climatic conditions.

Table 1. Dating results of Naminan site.

Unearthed layer	Sample type	Dating method	Year (a B.P.)
I	Pottery slices	Thermo-luminescence	9800 (uncorrected)
IV	Animal bone	^{14}C	13650±180 (corrected by INTCAL98)
V	Animal bone	^{14}C	18170±130(corrected by INTCAL98)
VI	Spiral shells	AMS ^{14}C	22720±490 (corrected by INTCAL98)

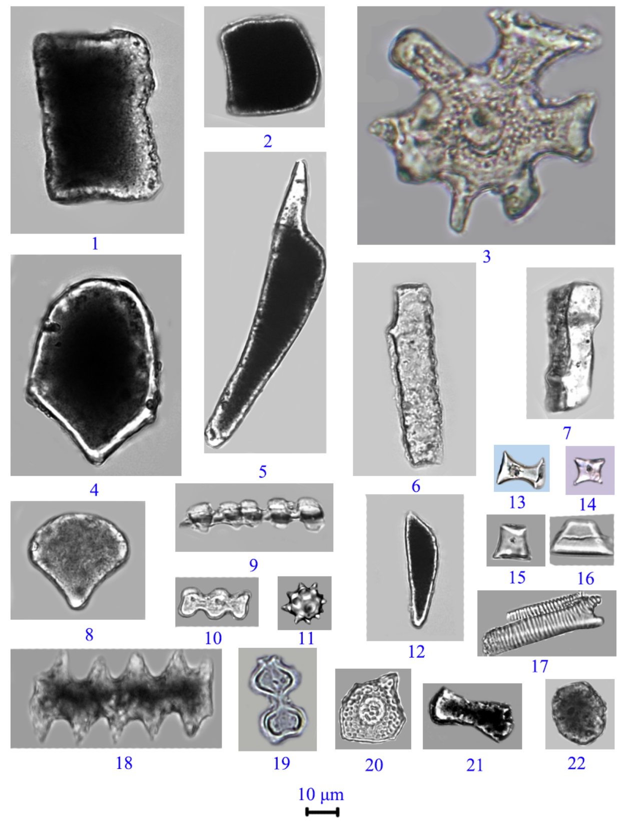

Fig. 3. Micrographs of phytolith morphologies at the Naminan site: 1. BLOCKY (rectangular), depth: 424 cm; 2. BLOCKY (BLOCKY [square]), depth: 170 cm; 3. woody plant, depth: 348 cm; 4,8. BULLIFORM FLABELLATE, depth: 216 cm; 5,12. ACUTE BULBOSUS, depth: 266 cm; 6. ELONGATE ENTIRE, depth: 250 cm;7. Pteridophytes, depth: 034 cm; 9. CRENATE, depth: 348 cm; 10. POLYLOBATE, depth: 424 cm; 11. globular echinate, depth: 008 cm; 13,14. SADDLE (short), depth: 170 cm; 15,16. RONDEL, depth: 400 cm; 17. TRACHEARY, depth: 216 cm; 18. ELONGATE DENTATE, depth: 386 cm; 19. BILOBATE, depth: 170 cm; 20. polygonal (Cyperaceae), depth: 400 cm; 21. SADDLE (long), depth: 146 cm; 22. spheroid, depth: 044 cm.

3.3 Phytolith analysis of archaeological sediments

By comparing the percentage of phytoliths in archaeological sediments with that in topsoil samples, the local warmth and humidity in different historical periods can be determined [23]. To facilitate a comparison with the modern climate, an index of warmth and humidity is defined as follows:

Warmth index = [percentage of warm phytolith types (BULLIFORM FLABELLATE + BLOCKY (square) + BLOCKY (rectangular)+ BILOBATE +SADDLE (long)+ SADDLE (short)) / percentage of cold phytolith types (spheroid + ACUTE BULBOSUS + ELONGATE ENTIRE + ELONGATE

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DENTATE + CRENATE + POLYLOBATE + RONDEL)] / [percentage of warm types in topsoil/percentage of cold types in topsoil] × 100. If the warmth index of a sample is greater than 100, it indicates a warmer climate than the present, and if the index is less than 100, it indicates a colder climate than the present.

Humidity index = [percentage of humid phytolith types (BULLIFORM FLABELLATE + BLOCKY (square)+ BLOCKY (rectangular) + BILOBATE + SADDLE (long) + Pteridophytes + Cyperaceae) / percentage of dry phytolith types (ACUTE BULBOSUS + SADDLE (short))] / [percentage of humid types in topsoil / percentage of dry types in topsoil] × 100. If the humidity index of a sample is greater than 100, it reflects a more humid climate than the present, and if it is less than 100, it reflects a drier climate than the present.

According to the percentage of variation in the main phytolith types, we generated the diagram shown in Fig. 4. Based on the sequence of archaeological layers from bottom to top, the phytolith assemblage characteristics for each layer were as follows:

Layer VI (depth 466–410 cm): Phytoliths that reflect warm and humid climate appeared in large numbers; these included BILOBATE (7.1%–39.1%, average 21.4%), BLOCKY (rectangular) (5.2%–20.7%, average 11.9%), BLOCKY (square) (4.5%–9.8%, average 7.1%), BULLIFORM FLABELLATE (0.2%–13.0%, average 5.8%), and SADDLE (long) (0.2%–8.7%, average 2.6%); cold phytolith types, such as ACUTE BULBOSUS (8.3%–18.1%, average 10.3%), ELONGATE ENTIRE (6.6%–17.6%, average 11.3%), ELONGATE DENTATE (0.4%–2.9%, average 1.9%), and spheroid (0.8%–7.1%, average 3.2%) were less common. Other common components included globular echinate (0.2%–14.3%, average 7.3%), CRENATE (0.6%–6.2%, average 3.7%), woody plant (2.5%–4.2%, average 3.6%), and TRACHEARY (0–0.8%, average 4%).

The warmth index of this layer ranged between 48.0 and 102.1, with an average of 67.8; the humidity index ranged between 5 and 99.5, with an average of 80.1. This shows that the climate in this period was slightly cool and dry compared with that in modern times, but it was still warm and wet throughout the whole section.

Layer V (depth 408–258 cm): The phytolith assemblage consisted of BILOBATE (0.4%–55.7%, average 12.5%), BLOCKY (rectangular) (0–14.3%, average 7.0%), BLOCKY (square) (0.7%–9.1%, average 5.0%), BULLIFORM FLABELLATE (0.6%–18.9%, average 5.4%), and SADDLE (long) (0.7%–5.1%, average 2.3%), reflecting a general decrease in warm and humid climatic conditions; cold types such as ACUTE BULBOSUS (0%–24.4%, average 13.7%), ELONGATE ENTIRE (0–20.0%, average 13.0%), ELONGATE DENTATE (2.7%–9.3%, average 5.5%) and spheroid (1.1%–8.4%, average 3.9%) increased as a whole. Other common components included globular echinate (0.4%–66.8%, average 18.6%), CRENATE (0.8%–8.8%, average 2.6%), and woody plant (1.4%–8.1%, average 4.3%).

The warmth index of this layer ranged from 7.5 to 76.3, with an average of 41.2; the humidity index ranged from 23.8 to 455, with an average of 92.3. Compared with Layer VI, the climate in this layer was colder, but the degree of humidity was higher, especially around 386 cm, with the peak value of the humidity index and the low-point value of the warmth index, indicating that there was an extreme climate event. Additionally, the number of globular echinate phytoliths in this layer increased significantly.

Layer IV (depth 256–190 cm): The phytolith assemblage consisted of BILOBATE (0.2%–16.7%, average 7.9%), BLOCKY (rectangular) (6.9%–11.8%, average 9.7%), BLOCKY (square) (5.1%–7.2%, average 5.9%), BULLIFORM FLABELLATE (0.9%–13.0%, average 6.3%) and SADDLE (long) (1.9%–3.2%, average 2.7%), reflecting a slight increase in warm and humid climatic conditions; ACUTE BULBOSUS (8.8%–22.5%, average 14.4%), ELONGATE ENTIRE (11.9–27.7%, average 19.8%), ELONGATE DENTATE (3.0%–8.3%, average 5.8%), and spheroid (2.8%–9.3%, average 4.7%), which reflect cold climate, were similar to those of the Layer V. Other common components included globular echinate (2.7%–27.2%, average 11.8%), CRENATE (0.5%–3.0%, average 2.1%), and woody plant (3.7–6.9%, average 4.7%).

The warmth index of this layer ranged from 28.2 to 42.8, with an average of 37.5; the humidity index ranged between 6 and 106. 6, with an average of 60.2.

Layer III (depth 188–76 cm): The frequency of globular

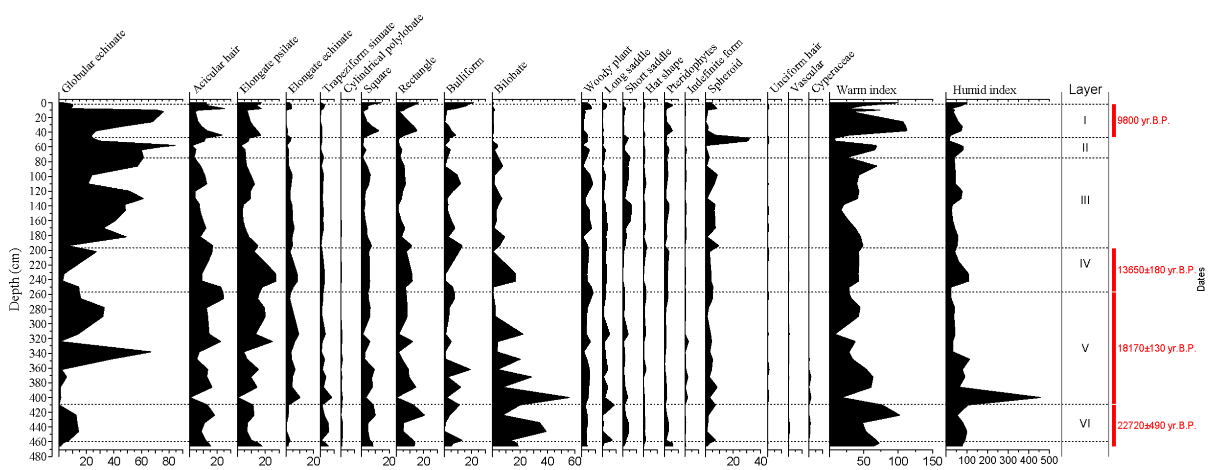

Fig. 4. Phytolith diagram of Naminan site.

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echinate phytoliths increased significantly, reaching 20.9%–57.1%, with an average of 43.3%. The contents of the other phytolith types decreased accordingly. Among them, the phytolith contents reflecting the warm and humid climate were BILOBATE (1.2%–8.9%, average 4.2%), BLOCKY (rectangular) (1.6%–6.9%, average 4.5%), BLOCKY (square) (1.7%–6.3%, average 3.5%), and BULLIFORM FLABELLATE (0.5%–11.9%, average 5.1%).The phytolith contents reflecting the cold and dry climate were as follows: ACUTE BULBOSUS (3.9%–12.5%, average 8.3%), ELONGATE ENTIRE (3.3%–12.1%, average 7.1%), ELONGATE DENTATE (2.0%–6.0%, average 4.0%), and spheroid (0.8%–8.5%, average 4.8%). Other common components included SADDLE (long) (0.2%-3.7%, average 2.0%), SADDLE (short) (1.3%-6.1%, average 3.6%), Pteridophytes (1.0%–3.4%, average 2.0%), and woody plants (0.8%–7.9%, average 4.4%).

The warmth index of this layer ranged from 16.7 to 48.5, with an average of 36.1; the humidity index ranged from 24.6 to 77.2, with an average of 47.3. Near 138 cm, the lowest values of the warmth and humidity indices appeared, which might correspond to a cold dry climate event.

Layer II (depth 74–48 cm): The content of globular echinate phytoliths in this zone was 24.3%–84.3%, with an average of 55.4%.The phytoliths reflecting a warm and humid climate were BILOBATE (0.3%–3.8%, average 2.4%), BLOCKY (rectangular) (2.0%–4.3%, average 2.7%), BLOCKY (square) (0.5%–3.0%, average 1.4%), BULLIFORM FLABELLATE (0.1%–3.5%, average 2.6%), and SADDLE (long) (0.1%–2.0%, average 1.1%).The phytoliths reflecting a cold and dry climate were as follows: ACUTE BULBOSUS (1.8%–11.6%, average 5.7%), ELONGATE ENTIRE (2.3%–8.3%, average 5.4%), ELONGATE DENTATE (0.5%–3.7%, average 2.0%), and spheroid (0.4%–32.0%, average 11.1%). Other common components included SADDLE (short) (0.8%–5.1%, average 2.4%) and woody plants (0.3%–5.5%, average 3.4%).

The frequency of cold phytoliths, such as ACUTE BULBOSUS, ELONGATE ENTIRE, and spheroid, increased significantly, especially the spheroid type. The warmth index of this layer ranged from 7.6 to 68.4, with an average of 50.4; the humidity index ranged from 16.1–81.9, with an average of 55.2.

Layer I (depth 46–2 cm): Globular echinate phytoliths in this zone were still abundant, ranging between 8.4% and 76.0%, with an average of 37.7%.The phytolith contents reflecting warm and humid climate were BILOBATE (0.1%–0.8%, average 0.7%), BLOCKY (rectangular) (2.3%–15.2%, average 9.4%), BLOCKY (square) (0.9%–12.5%, average 5.4%), BULLIFORM FLABELLATE (0.4%–17.5%, average 7.0%), and SADDLE (long) (0–2.9%, average 1.0%).The phytolith contents reflecting cold and dry climate were as follows: ACUTE BULBOSUS (4.1%–25.2%, average 12.4%), ELONGATE ENTIRE (5.9%–17.2%, average 12.2%), ELONGATE DENTATE (0–4.0%, average 1.5%), and spheroid (0–8.1%, average 3.3%). Other common components included Pteridophytes (1.1%–5.8%, average 3.1%), CRENATE (0–3.1%, average 1.2%), and woody plants (0.9%–7.1%, average 3.4%).

The warmth index of this layer ranged from 8.0 to 112.4, with an average of 61.7; the humidity index ranged from 15.9 to 88.2, with an average of 49.9. At the junction of this layer and Layer II (44–48 cm), the lowest values of the warmth index and humidity index appeared, indicating an extremely cold and dry climate event.

4 Discussion

4.1 Climate change reflected by the phytolith assemblage

From the perspective of the warmth index and humidity index, the paleoclimate of the Naminan site was generally colder and drier than the present. The cold and dry climatic periods reflected by Layers III and IV were the most significant, whereas Layers I and VI were relatively warm and humid. The climate during Layer V was colder than that during Layer VI; however, the precipitation might have been greater during the early period. Layer II was a transitional layer, and the climate changed dramatically during this period. The trajectory of climate change in the different layers of Naminan can be summarized as follows: warm and humid, followed by warm and cool and humid, cold and semi-humid, cold and dry, followed by warm and cool and semi-humid, and finally warm and semi-humid (Fig. 5).

Liu et al. reconstructed the vegetation and climate change history for the past 40000 years in the Menghai area of Yunnan Province through the study of pollen from lacustrine sediments [24]. The results show that local vegetation during the period from 27000–20650 a B.P. was dominated by a large number of mesophilous tree species such as *Cyclobalanopsis, Quercus, Castanopsis*, and *Ulmus*, indicating that the climate was relatively warm; from 20650–11870 a B.P., the large increase in *Dacrydium* pollen reflected a cold climate; from 11870–8270 a B.P., the decreased abundance of *Dacrydium* and increased abundance of *Quercus, Cyclobalanopsis*, and *Alnus* reflected the fact that the temperature began to rise again. Kuang et al. studied Late Pleistocene pollen in the Diancang Mountains in Dali, Yunnan Province [25]. The results showed that between 32–10 ka B.P., vegetation was mainly dominated by coniferous species such as Pinaceae and Pseudotsuga, and herbs and ferns mainly included Asteraceae, Poaceae, and Lycopodia. This reflects a cold and dry climate at that time, which became warmer and more humid after 10 ka B.P. Peng et al. studied the ostracods of the Heqing Basin in Yunnan [26]. They concluded that 60250–20190 a B.P. was a warm period and that 20190–11790 a B.P. was a cold period, which is comparable to the low value for the marine oxygen isotope stage at that time.

It is evident that climate change in Naminan is similar to that in other parts of Yunnan. Basically, it has experienced a process of warming followed by cooling and then warming.

In this study, we further refined the climate change sequence through phytolith analysis, and the intermediate cooling period was refined into the following sequence: warm and humid followed by cold and semi-humid followed by cold and dry. Based on the dating results, the age of the bottom Layer VI may correspond to the relatively warm marine oxy-

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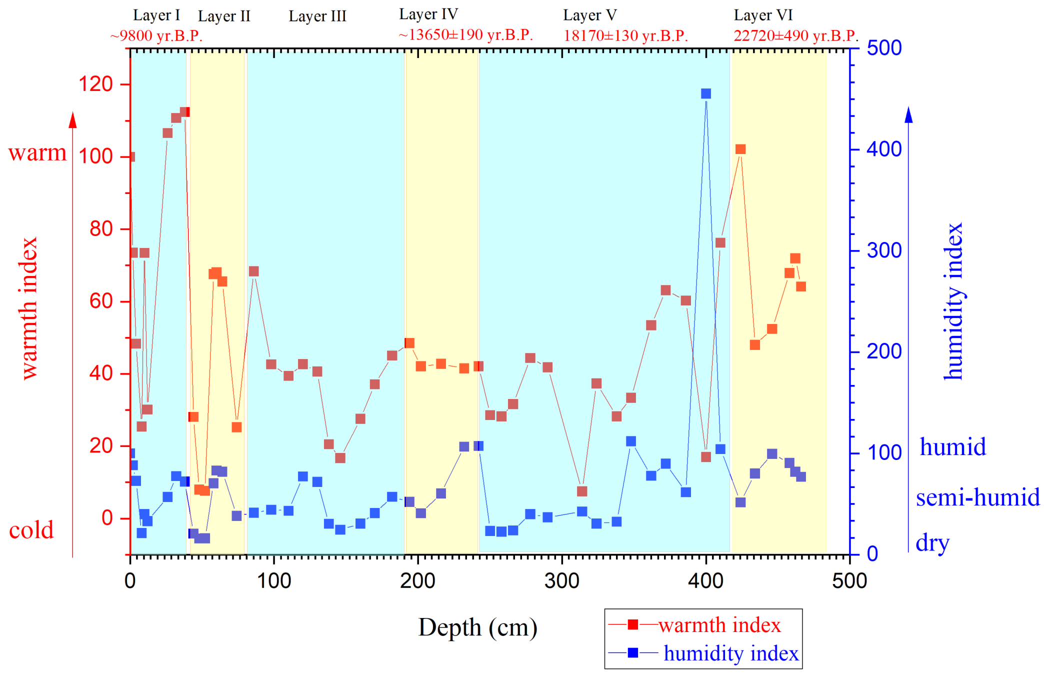

Fig. 5. Warm index and humid index in the different layers of Naminan cave.

gen isotope stage 2 (MIS 2); Layers V, IV, and III correspond to the coldest period during the Last Glacial Maximum; Layer II corresponds to the Last Deglaciation Period, and Layer I corresponds to the Holocene [6,27].

4.2 Paleovegetation and human activities revealed by phytolith analysis

Phytoliths are mostly deposited in situ, and a considerable fraction of phytoliths at archaeological sites is brought in by human activities. Therefore, in addition to reflecting climate change, phytoliths can also reflect the human activity. For example, BULLIFORM FLABELLATE phytoliths are of great significance for distinguishing wild rice from cultivated rice (*Oryza sativa*). In terms of their morphology, BULLIFORM FLABELLATE phytoliths from cultivated rice can be identified by a semicircular surface with numerous fish-scale decorations on both sides [28,29]. Some scholars once thought that Yunnan Province might have been one of the places of origin for rice cultivation [30]. The BULLIFORM FLABELLATE phytoliths at Naminan mainly belonged to the subfamilies Panicinae and Eragrostioideae, with a small number of Arundiaceae or Bambusoideae, and no BULLIFORM FLABELLATE phytoliths of Oryzoideae were found. Therefore, it can be inferred that ancient humans living in the Naminan cave might have neither mastered rice cultivation techniques nor used wild rice as a source of food.

Palm phytoliths (globular echinate) [31] are a special type among all types of phytoliths in Naminan, and their percentage changes drastically. The palm phytolith content was higher in all layers except in Layer VI, and it had no obvious relationship with climate change. This contradiction may be due to the intervention of human activities; that is, a large number of palm plants were brought in by human activities and deposited in archaeological sediments [32,33].

5 Conclusions

In this study, phytolith analysis was used as the primary research method, and topsoil phytoliths were used as a reference to determine warmth and humidity indices as a way of inferring the paleoclimate of the Naminan site. The climate of Layer VI was the warmest and most humid; it then experienced a process of climate change from warm and humid to cold and semi-humid to cold and dry to warm and semi-humid, and finally to warm and semi-humid. Through a process of comparison with nearby areas, we believe that the different climatic stages at Naminan correspond to periods of global climate change, such as the early MIS 2 period, the Last Glacial Maximum, the Last Deglaciation, and the Holocene.

Palm phytoliths appeared in large numbers at the site, although they had no obvious connection with climate change, as human activities might have been responsible for their deposition. In addition, no rice phytoliths were found at the site, indicating that humans might not have mastered rice cultivation techniques or used wild rice as a food source at that time. The relatively few dating results in this paper affected the detailed discussion of climate change and human activities, and we consider including them in future studies.

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