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The cooling fluctuation events during Holocene in the tropical zone of China

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Forty-eight samples are chosen to discuss the distribution in space and time of the cooling fluctuation events during Holocene in the tropical zone of China in this paper. The authors consider that the Neoglaciations II and III (or Cooling Event ①) have a widespread impact on the drop in temperature of 1-2 oC or less than 2 oC. The YD Event was dated at 11,300-10,200 a BP in the tropical mainland and its dating is 11,400-10,500 a BP in the sea area with a drop in temperature of 4-6 oC. The distribution of Event B and Neoglaciation I is taking a position of north, with a drop in temperature of 2.5-3.0 oC. The Cooling Event ② shows the temporality in time. The Cooling Event ③ shows the limitation of regional distribution with a drop in temperature of less than 1.5oC. The more recent the cooling event is, the smaller the drop amplitude in temperature will be. In the eastern part of tropical zone seven events are complete in all varieties but the cooling fluctuation is weaker in the western part. In Hainan Island and South China Sea the appearance of cooling fluctuations is synchronous with each other.

The cooling fluctuation events during Holocene in the tropical zone of China HUANG Zhen-guo, ZHANG Wei-qiang (Guangzhou Institute of Geography, Guangzhou 510070, China) 1 The instability of Holocene climate 1.1 The lower limit of Holocene It is suitable to take the dating of 11,000 a BP as the lower limit of Holocene in the tropical zone of China. For example, in a profile of Riyuetan of Taiwan Island the sporopollens are chiefly of the northern component before 11,000 a BP, after that the increase of warm or hot components shows the rise again in temperature by 2 oC. The terrestrial layer of upper Pleistocene of Longhai formation in Fujian province is dated at 11,293±560 a BP. In some cores in the Pearl River Delta the datings of the top part of terrestrial sand-pebble layer are dated at 11,620±380 a BP in Nanping of Zhuhai, 11,400±417 a BP in Zheyuan of Foshan and 10,900±150 a BP in Jiaotang of Panyu. The dating of top surface of weathering clay is 11,888 a BP in a profile of Lingdingyang. The transition surface from lower part of littoral facies to upper part of shallow marine facies in the ZQ4 profile in Zhujiang estuary basin is dated at 10,978±549 a BP. From archaeological data the datings of some fauna fossils representing hot-wet climate are 11,000 a BP in Dushizai cave of Yangchun, 10,950±300 a BP in Huangyandong cave of Fengkai, 11,310±180 a BP in Zhenpiyan cave of Guilin and 10,642±207 a BP of the "Sanya Man" in Hainan Island. In the sporopollen group of Waisha profile of Beihai in Guangxi the appearance of Rhizophaceae started at 10,500 a BP. The disappearance of Abies started at 11,465±116 a BP in Caohai profile in Kunming. Since 11,870±380 a BP the cool-loving Dacrydium dissolved in the profile of Manxing lake in Xishuangbanna. The profile of coral reef in Sanya of Luhuitou peninsula in Hainan Island shows an erosion surface with a buried depth of 11.6 m, the lower and upper layers of the erosion surface are dated at 12,230 a BP and 7,910 a BP respectively, so that the dating of the surface is deduced to be 11,000 a BP. In the profile of sea area north-west of Hainan Island, the Gothenburg Event (12,400-10,500 a BP) has been identified at the buried depth of 26.7 m and the bottom of the marine layer is dated at 10,570 a BP. The profile of HY4-901 (18o49´N, 113o28´E) in the northern part of South China Sea shows that the δ18O value decreased obviously below the depth of 1.66 m dating at about 11,000 a BP. The erosion surface with an elevation of -17.3 m in the core of Nanyong 1 of Yongshu reef in Nansha Islands is dated at 10,800 a BP, theδ18O value is -8.3‰ below the surface, but -5.2‰ above the surface. 1.2 Climatic fluctuation It is generally suggested that the last glacial maximum is 22,000-15,000 a BP followed by last deglaciation. But as to the issue of when it got warm again obviously after a cold spell and when Holocene began the opinions vary, the authors of this paper hold that the beginning of the Holocene is about 11,000 a BP. The climatic fluctuat

ion can be divided into three periods, i.e., the warming again, the rise in temperature and the drop in temperature (Figure 1). However the climate was instable in every period, even in the Megathermal period from 8,500 a BP to 3,000 a BP (maybe 8,500-3,500 a BP in China´s tropics), there were two main cooling fluctuation events. During the period of drop in temperature three warming events can be found also. Some researchers in recent years raised doubts about the warming stage of Sui and Tang dynasties. It is possible that the cooling fluctuaion of about one hundred years occurred during the warm period of about five hundred years. The pattern of climatic fluctuation consists of eight cooling stages and eight warming stages, of which each cooling stage is generally 200-500 years long. In this paper, 48 samples are chosen to discuss. In light of the limited precision of these data of Quaternary geological research, seven cooling stages are discussed only except the warming stage of the 13th century and the Little Ice Age in this case. Moreover it is difficult at present to define the dating of the beginning and the end of these cooling stages so that they are only called events of cooling fluctuation. The seven cooling stages are called events of YD, B, I, II, III (①), ② and ③ for short, respectively. Event means a short time, it can be evidenced by the appearance of tropical faunas even in cooling period. For example, there was Elephax maximus during the Neoglaciation II (4,200-4,000 a BP) in Guangdong´s Hetang of Foshan and Maogang of Gaoyao; during the Neoglaciation III, in Minle of Nanhai of Guangdong (2,500 a BP) and Wuzhou in Guangxi (2,770 a BP); during cooling stage ②, in Shixing of Guangdong (1,620-1,565 a BP) and Quanxian and Binyang in Guangxi (1,400 a BP); and during cooling stage ③, in Longxi, Longyan, Zhangzhou, Haicheng in Fujian, Huadu, Yangjiang, Leizhou in Guangdong, Bobai in Guangxi (1,000-800 a BP) as well as Huizhou (1,009 a BP), Dongguan (1,093-1,040 a BP) in Guangdong and Qinzhou (826-811 a BP) in Guangxi. 2 Examples of cooling fluctuation events 2.1 Taiwan Island The following examples reflect the influence of the Neoglaciation II. The number of sporopollens in the profile of Riyuetan shows that the annual mean temperature was 2.5oC higher than that at present in the Megathermal (5,500 a BP), afterwards the temperature dropped till 3000 a BP and then the same as to the present. A gap has been found between the Dapenkeng Culture (7,500-6,000 a BP) of middle Neolithic and the Yuanshan Culture (4,000-3,100 a BP) of late Neolithic Age in Taiwan Island (Huang et al., 1995). In the profile of Dagui lake of Maolin in Gaoxiong the alternation of white layer and black layer can be seen, the relative brightness index (RBI) of the sediments reflects the climatic change (Luo et al., 1996). The curve shows (Figure 2a) the Neoglaciation III occurred before 2,500 a BP, Cooling Stage ② from 1,700 a BP to 1,400 a BP and Cooling Stage ③ from 1,120 a BP to 800 a BP, but the climatic fluctuation was quite obvious. The amplitude of drop in temperature due to these three cooling events is less than that of the Little Ice Age. Fifty-six datings of Holocene coral reefs indicate that it is difficult to divide their evolution stage except the concentrated stage dating at 6,000-5,000 a BP, showing an insignificant cooling fluctuation during Holocene. For the formation of coral reefs, the sea water temperature of 18 oC is required at least, at present the temperature of sea surface water in January is about 20 oC so that the amplitude of temperature drop during Neoglaciation was not over 2 oC (Huang et al., 1995). 2.2 Fujian Province The curve of sporopollens and climate in Langqi of Fuzhou shows three temperature drop events at 9,000 a BP, 7,500 a BP and 5,000 a BP represent the Event B, Neoglaciations I and II, respectively (Huang et al., 2001). The lower concentration curve of Haicheng in the estuary plain of Jiulongjiang river shows that the datings of the three values of sporopollens at 7,154 a BP, 4,000 a BP and 2,500 a BP reflect the Neoglaciations I, II and III. Large amount of sporopollens of Pinus and deciduous tree of Castanea occurred in the profiles of Houyu in Fuzhou and Houzhu in Putian during 5,000-4,000 a BP. At present the annual mean temperature in the distribution area for this type of vegetation is 1-2 oC lower than that of coastal zone in central Fujian (Huang et al., 2001). Sixty-five tree stools of Keteleeria dating at 7,620-7,138 a BP have been found in the remains of ancient forest on the sea floor of Shenhu Bay in Jinjiang. This kind of hydrophilic and cool-loving forest is distributed in mountainous area above 500 m at present, representing a drop of 2-3 oC in temperature during Neoglaciation I so that there was a dense forest of Keteleeria in the coastal lowland at that time (Huang et al., 2001). In the archaeological remains in Tanshishan of Minhou some fauna fossils such as Elephax maximus and Cerous unicolor dating at 3,270-3,090 a BP have been found but afterwards these faunas disappeared, showing the advent of Neoglaciation III. The north limit of producing area of litchi was located at Fuzhou and Ningde during the warm period from the end of Tang Dynasty to Song Dynasty, however the litchi trees froze to death extensively in 1,110AD and 1,178AD (890-820 a BP) and afterwards the north limit moved southward to south of Putian (Wang, 1990), representing the Cooling Stage ③ with a drop of 0.8oC in temperature according to the moving distance in latitude.
2.3 Guangdong Province The profile of Chenghai in Hanjiang delta shows that growth and decline of the sporopollens of Quercus and Rhizophaceae occurred synchronically one another (Figure 2b) (Zheng, 1990). The Quercus decreased suddenly at about 9000 a BP, showing probably the Event B. Both curves appear obviously low value during 8,000-6,700 a BP, showing the Neoglaciation I. The Quercus decreased suddenly once again at 4,000 a BP showing probably the Neoglaci

ation II. The curve of δ13C in the profile of Batou of Chenghai reflects a warming trend before 1,130 a BP, showing the warm period in Shui and Tang dynasties. Afterwards several severe cooling fluctuations appeared during 1,130-810 a BP, representing the Cooling Stage ③, and then the temperature dropped especially after 500 a BP showing the Little Ice Age (Figure 2c) (Huang et al., 2000). The sporopollen groups in the profile of Jiaotang of Panyu in the Pearl River Delta shows that growth and decline of the broad-leaved deciduous forests of Castanea and Quercus occurred synchronically one another (Figure 2d) (Shi et al., 1992). The higher contents of both during 4,600-4,000 a BP and 3,200-2,500 a BP represent the Neoglaciations II and III respectively. The higher content of Quercus during 1,700-1,400 a BP and higher content of Castanca during 1,100-800 a BP represent the Cooling Stages ② and ③, respectively. Two layers of buried putrid woods dating at 6,510-5,940 a BP and 2,350-2,050 a BP have been found in the Holocene sediments of the Pearl River Delta, the former shows the withered trees in the Neoglaciation II, and the latter appears catastrophically in Cooling Stage ②. The remains of kitchen midden culture of the Neolithic Age began to appear in the Pearl River Delta and Hong Kong area at about 6,500 a BP, reaching the climax at 4,000-3,500 a BP, but decreasing suddenly during 4,500-4,000 a BP. Besides, the pure yellow sand layer basically free from cultural remains contained in the dune culture deposits is dated also to be 4,500-4,000 a BP. This phenomenon of "missing link" and "barren bed" is probably related to environmental catastrophe, including the cooling of climate and eustatic change. The curves of δ180 and vanadium content in the profile of Futian in Shenzhen show clearly the appearance of the Neoglaciation II with a temperature drop of about 2 oC at 4,400 a BP or 4,100 a BP, as well as facilitate the identification of the Neoglaciation III (2,500 a BP) and the Cooling Stage ② (1,900 a BP) (Figure 2e) (Huang et al., 2000). In a profile of Hugangyan lake of Leizhou peninsula, the content values of total orgnic carbon, total nitrogen and biogenic silica in the layer of 7.48-7.96 m deep and dated to be 11,300-10,200 a BP are all the minimum, an indication of the Younger Dryas (Wang et al., 2001). Besides, in the profile of Dingnan in Jiangxi, which borders Guangdong, the YD Event continued for several hundred years from about 10,400 a BP. Before 10,400 a BP the sporopollen content of Alnus, which is broad-leaved deciduous arbor tree, accounts for 80% of the woody plants excluding evergreen trees such as Castanopsis, Cyclobalanopsis etc. The Alnus increased sharply to 95% at 10,400 a BP and the evergreen trees disappeared essentially. Afterwards the Alnus decreased to 50%, Castanopsis, Cyclobalanopsis etc. account for 8-10%. The distribution elevation of Alnus forest is above 1,300 m at present and the elevation of this profile is only about 300 m, hence a drop of temperature of about 6 oC due to the YD Event (Xiao et al., 1998). 2.4 Guangxi Zhuang Autonomous Region The profile of Waisha in Beihai shows (Figure 2f) (Mo et al., 1996) that the sporopollens of Rhizophaceae were identified 10,500 a BP with content increasing from 0.9% to 2.1%, but a low value of sporopollen density occurred at 5,000 a BP, an indication of the Neoglaciation II. Influenced by the Neoglaciation III, Rhizophaceae disappeared during 3,400-1,900 a BP, and then the low content at 1,100 a BP represents the Cooling Stage③. The curves ofδ180 andδ13C of a stalagmite from Xiangshui cave of Guanyang in Guangxi show the appearance of YD Event at 11,500 a BP (Figure 2g) (Zhang et al., 1998). Calculated according to a temperature change of 1 oC resulting from a change of δ180 value of 0.6‰, the temperature dropped by about 4 oC at that time than that at present. The YD Event ended at 10,800 a BP and then the curves appear frequent fluctuation but the value ofδ13C reflects three cooling fluctuation events, namely, 5,000 a BP, 4,000 a BP (Neoglaciation II) and 3,100 a BP (Neoglaciation III), the change amplitude of temperature was less than 1.5 oC. 2.5 Yunnan Province The profile of Manxing lake of Menghai in Xishuangbanna reveals a decrease of sporopollens of thermophilic Altingia, Syrtaceae and Myrtaceae and increase of cool-loving Alnus. Cyclobalanopsis and Quercus etc. at 4,670 a BP (Tang, 1992), representing the Neoglaciation II. The profile of Dianchi Lake in Kunming shows a sudden decrease of various kinds of sporopollens during 5,300-5,000 a BP, reflecting the advent of Neoglaciation II. The tropical component disappeared at 3,900 a BP, the content of evergreen broad-leaved trees of Cyclobalanopsis, Castanopsis etc., dropped to the minimum level since 12,000 a BP. The deposition ratio dropped from 2,900 grains/cm2·a to 860 grains/cm2·a at 3,800 a BP, also an indication of Neoglaciation II. The thermophilic Carya and Trachycarpus disapeared at 1,700 a BP, the former is distributed in southeastern Yunnan at present (Wu et al., 1991). The curve of δ13C in the profile of Erhai Lake reveals two values of rich-light isotope at 5,300 a BP and 1,700 a BP (Figure 2h) (Zhang et al., 1998), representing the Neoglaciation II and Cooling Stage ② respectively. The drop of about 1.5 oC in temperature is deduced acoording to the changing value ofδ13C. The faunas from the archaeological remains of Dadunzi in Yuanmou and of Xihu in Jianchuan dating at 3,210 a BP and 3,115 a BP respectively, are chiefly Macaca mulatta, Cervus unicolor etc., which are similar to those at present, however Elephax maximus and Axis disappeared, reflecting the influence of Neoglaciation III (Huang et al., 2001). 2.6 Hainan Island According to different diatom association of cold-water species and warm-water species from the profile in the sea area northwest of Hainan Island, a temperature curve of sea surface water can be drawn (Figure 3a) (Chen et al., 1988). From the curve the YD Event (10,570 a BP), Neog laciations I (7,200 a BP) and III (2,800 a BP) have been recognized. The curves of $\delta^{13}C$ and $\delta^{18}O$ from the profile of coral reefs in the northern coast of Leizhou peninsula in Sanya show an obvious drop of temperature during Neoglaciation II at about 4,000 a BP, the oxygen and carbon isotopes tended to be enriched heavy-isotope reflecting the cold-dry climatic desiccation due to the decrease of summer rainfall with enriched slight-isotope (Figure 3b) (Huang et al., 2001). 2.7 South China Sea The profile RC-26-16 in the northern part of South China Sea (19o53´N, 118o01´E) indicates the YD Event at 11,400 a BP with a drop of about 6 oC than at present (24.6 oC) in winter sea surface temperature, and the Neoglaciation I (8,000 a BP), Neoglaciation II (4,000 a BP) and Cooling Stage ②, with a drop of the temperature of 2.5 oC, 3.0 oC and 0.5 oC respectively (Figure 3c) (Wei et al., 1999). From the profile V36-06-3 (19o00´N, 116o05´E), three cooling events can be identified, namely, the YD Event at 10,500 a BP, the winter temperature of sea surface water dropped to 18.1 oC, lower than that at present (23.1 oC) by 5 oC; the Neoglaciation II (5,000 a BP); and the Neoglaciation III (2,500 a BP) with water temperature of 23 oC, the same as present (Figure 3d) (Wang et al., 1994). The curve of winter water temperature from the profile RC12-350 in the southern part of South China Sea (6o32´N, 111o13´E) shows that the temperature was 26.5 oC at 5,660 a BP and then dropped to 25.5 oC at 4,750 a BP, representing the Neoglaciation Ⅱ when the water temperature was 1.5 oC lower than that at present (27 oC). Another profile 17962 near RC12-350 shows that the export productive forces of sea surface water decreased from 17gC/$cm^2 \cdot a^{-1}$ before 5,350 a BP to 11 gC/$cm^2 \cdot a^{-1}$ at 5,350 a BP, also representing the Neoglaciation II (Jian, 1992). From the profile of Nanyong 1 borehole of Yongshu reef in Nansha Islands (9o32´N, 112o52´E) two samples are collected at the depths of 12.1 m and 6.5 m dating at 4,770 a BP and 3,950 a BP respectively. The analysis of foraminifera shows that these two samples of higher abundance of dihydroxy amino acids of foraminifera represent the Neoglaciation II (Figure 3e) (Zhu et al., 1997). 3 Conclusions As shown in Figure 1, the Neoglaciations II and III experienced widespread cooling fluctuations during Holocene in the tropical zone of China. Both the beginning and the end of these events are essentially the same in several regions, showing the intense fluctuations of climate during 6,000-2,500 a BP, which is consistent with the recognition of the previous researchers about the climate characteristics following the climax of the Megathermal of Holocene. For reference the three samples of the YD Event in Hugangyan, Dingnan and Guanyang in the mainland are described only but of which two samples are further away from north to the tropical zone. As for the sea area, according to the data from the northern part of South China Sea and Beibu Bay, the YD Event from 11,400 a BP to 10,500 a BP appeared earlier and lasted for a long period of time probably due to the susceptibility of tropical ocean to the cooling event. The samples of Cooling Event B and the Neoglaciation I in the mainland can be seen only in northern Fujian and eastern Guangdong. The dating of Cooling Stage ② is 1,900-1,700 a BP, showing the temporality. The Cooling Stage ③ occurred in Taiwan Island, Fujian, Guangdong and Guangxi, showing the limitations of regional distribution further northward. In the eastern part of the tropical zone the seven cooling events are complete in all varieties especially in Guangdong. While the cooling fluctuation was quite weaker in the western part of the tropical zone. There are six samples in Yunnan of which only one sample, the profile of Menghai with one cooling event of the Neoglaciation II at 4,670 a BP is within the tropical zone. The processes of cooling fluctuations were synchronous with each other in Hainan Island and South China Sea, showing the consistent change of climate in the central tropical zone. Compared with present situation, the drop amplitude in temperature was 5-6 oC in South China Sea and 4-6 oC in Guanyang and Dingnan due to the YD Event, which is the same to the drop amplitude of 6 oC in South China Sea during the last glacial maximum. The drop amplitude during the Neoglaciation I was 2-3 oC in Fujian and 2.5 oC in the northern part of South China Sea, and then during the Neoglaciation II it was 1-2 oC in Fujian, 2 oC in Shenzhen, 1.5 oC in Guangxi and Yunnan, and 0.5-1.5 oC in South China Sea. As for the Cooling Stages ①, ② and ③, the temperature dropped by less than 2 oC in Taiwan Island, 0.8 oC in Fujian, less than 1.5 oC in Guangxi and Yunnan or the temperature was the same to that at present in South China Sea. From the above-mentioned facts it can be seen that the more recent the cooling event is, the smaller the drop amplitude in temperature will be. References Figure 1 Climate periods of Holocene and cooling fluctuation events in the tropical zone of China Figure 2 Examples showing the cooling fluctuation events in Taiwan Island and the mainland Figure 3 Examples showing the cooling fluctuation events in Hainan Island and South China Sea

关键词： cooling fluctuation; tropical zone; China