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The 5.5 cal ka BP climate event, population growth, circumscription and the emergence of the earliest complex societies in China

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Abstract The emergence of complex society is a milestone in the history of human society evolution. China is one of the few regions in the world where the earliest complex society appeared; however, its driving mechanisms remain unresolved. On the base of available evidence from both archaeology and Holocene climate, in combination with agency theory, this study attempts to address the driving mechanisms for the simultaneous emergence of complex societies in multiple areas of China around 5.5 cal ka BP. It is hypothesized that three factors, including climate change, population growth, and circumscription, jointly act and cause regional population-resource imbalance and trigger inter-group conflicts and wars. Such competitions provide the opportunity for some power-pursuing agents to break the restriction of social leveling mechanism and to become the centralized decision-making leaders, which further lead to the emergence of incipient large-scale complex societies. Increase in extreme climate events during 6.0–5.0 cal ka BP cooling period causes frequent occurrence of resource stress and increase in the frequency of inter-group competitions, which creates conditions for the legitimation, institutionalization, and persistence of centralized leadership, and finally leads to the formation of persistent institutionalized inequity. Our research result can explain not only the process and mechanism of complex society formation, but also two phenomena which cannot be reasonably explained by previous theories, that are, why the earliest complex societies in China emerge around 5.5 cal ka BP, and why they appear simultaneously in multiple regions.

Keywords 5.5 cal ka BP climate event, Population growth, Circumscription, Complex society, Driving mechanisms

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1. Introduction

"Complex society" or "Social complexity" refers to the changing process from simple to complex society and a particular stage of society evolution. "Complexity" includes two concepts of heterogeneity and inequality. The former refers to the population constitutions among social groups, and the latter refers to differential ways of acquiring natural and social resources within a society (McGuire, 1983). The complex society under discussion in this paper mainly concerns the emergence and persistence of institutionalized inequality (Mattison et al., 2016), in which the institutionalized leaders are considered to be an essential component to the emergence of inequality or complex society (Vaughn et al., 2009).

Researches indicate that since 100 thousand years ago after

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the emergence of modern human (Boehm, 1999), or even more than 2 million years ago (Hayden, 2001), human have been living in an egalitarian society as bands or tribes. Such egalitarian society had remained until around 5.5 cal ka BP, when distinct complex societies appear near simultaneously in multiple regions on the globe (Sandweiss et al., 1999; Brooks, 2006), indicating an evolution of human society from equality to inequality. This event has been generally acknowledged as an important milestone in the history of human society evolution. Recently, archaeological community highlights the driving mechanisms behind the emergence of complex society as one of 5 grant challenges for archaeological research in the coming 25 years (Kintigh et al., 2014).

China is one of the few regions in the world where the earliest complex society independently evolves. A large quantity of archaeological evidence indicates that complex societies emerged simultaneously around 5.5 cal ka BP in a number of areas in China (Chen, 2003; Liu and Chen, 2012; Luan, 2012), marking the origin of ancient Chinese civilization (Yan, 1999; Luan, 2012; Chen, 2003). Such development lays the foundations for the further development of civilized society in the subsequent Xia-Shang-Zhou three dynasties (Yan, 1999).

However, the driving mechanisms for this milestone-like event of human society evolution remain unresolved (Chen, 2003; Liu and Chen, 2012). In recent years, with the increase of accurately-dated and highly-resolved paleoclimate records, as well as accurate determination of absolute timing sequence of archaeological cultures, researchers find that the climate change around 5.5 cal ka BP is synchronous in timing with the emergence of complex societies in multiple regions around the globe (Kennett and Kennett, 2006; Kůper and Kröpelin, 2006), including China (Sandweiss et al., 1999; Wu and Liu, 2002; Brooks, 2006). Based on these findings, they further suggest a possible causal links between them from the perspective of climate change impact and adaptation. However, such kinds of hypothesis have been seriously questioned for two main reasons. On the one hand, such theories usually fall into environmental determinism because they only consider climate changes and neglect the effect of other factors, especially population growth; in addition, these theories concern with group level explanations (methodological collectivism) by assuming all the people as faceless passive responders. On the other hand, these kinds of hypothesis usually assume that interpersonal inequality already exists in the human group; therefore, it cannot explain how inequities become established in the first place (Wiessner, 2002; Kantner, 2009).

By contrast, the agency theorists suggest that humankind itself is the main driving force of human society evolution (Vaughn et al., 2009). They prefer individual level explanations (methodological individualism), and suggest that there are some self-aggrandizers (Clark and Blake, 1994) or self-accumulators (Hayden, 1995) within the populations. Driven by human's inherent self-interests, they pursue prestige, power, and high social status, whose actions are the main driving force of society evolution (Wiessner, 2002; Kantner, 2009). Compared with adaptation theory, agency theory can partly explain the emergence of initial social complexity. However, it often neglects the restrictive effect of social structure and natural factors on individual agency. It usually considers the egalitarian society as a simple society with rather weak structural constraints, in which human individual can freely exercise its initiatives and lead to society evolution (Wiessner, 2002; Kantner, 2009). However egalitarian societies have been operated successfully for at least more than 100 thousand years, their structures are extremely complex and individual initiative is unlikely to easily break structural restrictions (Boehm, 1999). Therefore, it is necessary to understand the context that provides the opportunity for agents to exercise their initiatives (Kantner, 2009).

In this paper, we first summarize and analyze the archaeological evidence of emergence and persistence of complex societies, as well as intergroup conflicts and wars around 5.5 cal ka BP, which lend a support to the war theory; then we identify the 5.5 cal ka BP climate event on the base of Holocene climate records; finally, we propose an alternative hypothesis for driving mechanisms behind the evolution of complex societies in China by combining demographic and agency theory.

2. The emergence of complex societies in multiple regions around 5.5 cal ka BP

A large quantity of archaeological evidence indicate that Neolithic cultures in a number of areas in China experienced a nearly simultaneous pronounced transition around 5.5 cal ka BP, which marked social evolution from previous egalitarian into permanent institutionalized unequal societies.

In the middle-upper reaches of Weihe River, a three-tiered regional settlement hierarchy in terms of size and structure emerged at the Dadiwan site in Qin'an, Gansu Province in the middle-late Yangshao culture phase (5.8–4.9 cal ka BP). Its largest house (F901) covered an area of 290 m^2, thought likely to be a large-scale palatial building (Yan, 1999), or a central place for activities of regional communities (Liu and Chen, 2012). In front of this foundation, there was a large-scale square with an area about one thousand square meters, indicating that it was probably used as a large public plaza for communal activities (Liu and Chen, 2012). The emergence of Dadiwan site reflected settlement differentiation and obviously increased social complexity as compared to previous egalitarian societies.

In the Lingbao area of western Henan Province, obvious social complexity occurred around 5.3 cal ka BP in the mid-Yangshao period, which was manifested in three aspects: firstly, it showed obvious regional settlement hierarchy in terms of covering area and spatial distribution of the settlements. For example, the largest Beiyangping settlement covers an area of nearly 1 million square meters; secondly, differentiation also occurred within settlements, in which extra-large-sized houses appeared with the indoor area of F105 covering about 200 m^2; thirdly, human rank differentiation emerged. For example, obvious differences in mortuary patterns were found in the 34 tombs within the Xipo cemetery (Luan, 2012; Li, 2016). In particular, burial evidence may indicate that rank hereditary phenomena appeared. For example, in a large-scale tomb of Xipo Village, 3 jade axes were buried with the tomb owner of only 4-years-old (Wang, 2014). These artifacts were inherited since a child could not acquire the right to possess these objects (Marcus, 2008).

In the Zhengzhou area of Henan Province, a rammed-earth walled-settlement of 25 hectares appeared in the late stage of Yangshao culture (5.3–4.8 cal ka BP) (Yang, 1997). The emergence of such fortified settlement indicated that technology, social organization, and leadership have reached a considerable level, which was usually considered by Chinese archaeologists as an important indicator of emergence of complex society (Liu, 2005). In addition, unearthed human bones showed that human sacrifice may have started at that time (Yang, 1997; Liu, 2005).

In Haidai area of the lower reaches of Yellow River, the process of social complexity evolution started around 5.5 cal ka BP in the middle stage of Dawenkou culture. Its archaeological manifestations mainly included 4 aspects: (1) field survey of the archaeological sites revealed that at least two-tiered regional settlement hierarchy appeared in multiple regions of Shandong Province. For example, the settlement size of late Dawenkou cultural stage in the central region of Shandong ranged from 1 to 80 hectares (Underhill, 2002). (2) Different tombs in the Dawenkou cultural period (6.0–4.6 cal ka BP) showed an obvious difference in both quantity and quality of burial objects. For example, the male owner of tomb M2005 in Dawenkou site of Tai'an had burial objects as many as 103, significantly more than that of the ordinary tombs (Luan, 2012). (3) Among the professionally-made pottery products of Dawenkou culture there were some exquisite ceramic wares, jade wares, bone-horn wares, as well as ivory sculptures, which were luxury goods used by chiefs or aristocrats. Their appearances implied social stratification (Underhill, 2002; Luan, 2012). (4) Elite-controlled exchange of valuable articles during the Dawenkou period also appeared (Liu, 2005).

The Lingjiatan site located in Hanshan of Anhui Province covered an interval of 5.6–5.3 cal ka BP. Altar, cumulated stone circle, and large tombs with a large quantity of stone wares were unearthed, among which the 07M23 had 330 pieces of burial articles including 200 jade wares and a jade pig 72 cm long and as heavy as 88 kg (Luan, 2012). These finely made jade wares indicated that the technology and specialization have reached a high level, and these ceremonial exquisite jade wares appeared only in a few well-equipped large tombs, implying the emergence of leaders and their controlling power over the ceremonies (Liu and Chen, 2012).

In the Circum-Taihu Lake area of the lower reaches of Yangtze River, obvious social complexity around 5.5 cal ka BP during the mid-late stage of Songze culture was manifested by the distinct differentiation in settlement pattern, mortuary patterns, and burial differentiation. They were shown mainly in two aspects: Firstly, graveyards were differentiated into large and small tomb districts, indicating the differentiation of individual ranks. Secondly, the burial articles from different tombs in the same graveyard also showed obvious difference, and some tombs had abundant funerary objects with higher standards, for example, M91 had 38 pieces (sets) of burial objects, including 14 jade wares (Luan, 2012).

In the Jianghan area of the middle reaches of Yangtze River, regional settlement hierarchy in terms of settlement size occurred around 5.5 cal ka BP during the Daxi cultural period. Chengtoushan walled and moated settlement was found, inside which burial differentiation also started to appear among more than 200 tombs (Luan, 2012).

In west Liaoning Province during the middle stage of Hongshan culture around 5.5 cal ka BP, large ritual buildings, stone tombs, and tombs with fine burial jade wares appear (Nelson, 1995; Yan, 1999). Nelson (1995) suggested that the tombs at Niuheliang site indicated that a small number of society elites controlled the production of elaborated handcrafts.

In summary, increasing archaeological evidence indicated that the fourth thousand year BC, especially its later half, witnessed an important evolution process for the prehistoric Chinese societies. Several major cultural regions of China all experienced nearly synchronous rapid development (Luan, 2012), which led to the emergence and persistence of initial complex societies. Moreover, such evolution process occurred abruptly (Luan, 2012). Some researchers suggested that some societies even evolve into chiefdoms (Chen, 2003; Underhill and Habu, 2006). Archaeological and historical research communities in China generally referred to the emergence of such complex societies as the origin of civilization, and described the simultaneous emergence of complex societies in multiple regions as "the sky full of stars" civilization origin mode (Su, 1999).

3. Archaeological evidence of inter-group conflicts and wars

Evidence about inter-group conflicts and wars is an important support for the war theory of social evolution. However, its archaeological manifestations are often severely ambiguous or lacking due to the difficulty of preserving some of the wooden weapons and the fact that some unprocessed stones are used as weapons. In addition, artifacts usually have multiple utilizations, which make an explicit interpretation of the archaeological evidence very difficult. Such two phenomena usually lead to a serious underestimation of the war's role in prehistoric social evolution (LeBlanc, 1999)

Therefore, various lines of archaeological evidence about wars should be synthesized and particularly the mutually-supporting evidence should be highly considered (LeBlanc, 1999; Wu and Ge, 2014). On the base of these principles, we summarize and analyze multiple lines of archaeological evidence from major Neolithic cultural areas in China, and find obvious increase in inter-group conflicts and wars during 6.0–5.0 cal ka BP. These evidences include practical weapons, weapons symbolizing military and reign powers, defensive settlement walls and moats, abnormal deaths, etc.

3.1 Emergence of stone or jade axes

One of the most obvious archaeological war evidence during the interval of 6.0–5.0 cal ka BP was the proliferation of funerary weapons. Generally, it was very rare to find weapon burial before 6.0 cal ka BP, while after that time finely-made stone or jade axes were commonly utilized for burial in the Yangshao Culture of central China, Dawenkou Culture of Shandong Province, Songze Culture of Jiangsu-Zhejiang Province, Xuejiagang Culture of Anhui province, and the Daxi Culture of Hunan and Hubei provinces (Qian, 2000, 2009). In the Hongshan culture of the western Liaoxi area where war evidence was previously thought lacking, a complete set of stone axes with decoration at its handle end, as well as a headless human skeleton was excavated in tombs recently, strongly implying the occurrence of conflicts (Wang, 2016). Ceremonial stone axes and jade axes evolved from stone axes and initially used for chopping were now widely used in wars due to their powerful killing ability in close combating (Okamura, 1997; Ma, 2000; Qian, 2000, 2009). Moreover, because axe can more easily show power and strength, a part of its function was elevated to be a symbol of power and social status, that is Yue (ceremonial axe) (Okamura, 1997; Qian, 2009). The burial articles for important persons were generally the most precious goods in societies of that time, therefore, the burial stone and jade axes became an important symbol, proving the existence of military leaders and indicating that coping inter-group conflicts and wars have become the most important issue for the tribe survival. The presence of these symbolizing weapons thus indirectly proved the prevailing of conflict and war in that time period (Okamura, 1997; Qian, 2009).

3.2 The construction of defensive facilities-walled-settlements and moats

Fortified facilities are those constructions utilizing natural or man-made obstacles to prevent others entering the settlement, which are considered as the most direct and concrete material evidence of inter-group conflicts (Field and Lape, 2010). Archaeological evidence indicated that the earliest walled settlements emerged during 6.0–5.0cal ka BP in both northern and southern China. In the south, the Chengtoushan walled-settlement in Li County of Hunan Province belongs to the Daxi-Qujialing culture period; it was first constructed around 6.0 cal ka BP, and was considered as the earliest walled-settlement in China (Liu and Chen, 2012). In addition, there was a moat surrounding the city (Hunan Institute of Cultural Relics and Archeology, 2007), which was the most typical double fortification facility commonly seen in Chinese history. These two lines of archaeological evidence combined clearly indicated the prevailing of fierce inter-group conflicts. In Zhengzhou area of Henan Province in the northern China, the Xishan walled-settlement with a moat belonged to the mid-late Yangshao period (5.3–4.8 cal ka BP), which also had a double defense system (Ma, 1997). In addition, discarded human bones were found in more than 10 excavation pits, among which some skeletons were either apparently in struggling posture or incomplete, and body and head were separated. Such human skeleton evidence further proved the occurrence of fierce inter-group conflicts (Yang, 1997). In the mid-lower reaches of Yangtze River where the Liangzhu culture (5.3–4.6 cal ka BP) is located, recent excavation revealed walled-settlements at approximately 5.0 cal ka BP (Liu et al., 2014), probably belonging to the same time interval. In other major cultural regions, although walled-settlements of this period have not been found at present, defensive moats appeared in all major culture regions (Ma, 1998; Qian, 2003). In Hongshan culture populated areas, where war and conflict evidence was previously considered very lacking, a large-scale moat was recently discovered in the Weijiawopu site in the Chifeng area of Inner Mongolia (Cheng et al., 2014).

3.3 Additional evidences

Additional evidence for violent conflicts during 6.0–5.0 cal ka BP was also unearthed in different cultural regions of

China. In northern Jiangsu Province at the Dadunzi site, which belongs to the Dawenkou cultural stage, a human thigh bone pieced by an arrow head was unearthed (Underhill, 2002); In the Central China, disorderly buried human bones were found at the above-mentioned Xishan walled-settlement (Yang, 1997) and randomly-disposed human skeletons were found in a dump pit of the Miaodigou site (6.0–5.3 cal ka BP) (Chen, 2013). Also in the Central China, a finely painted picture of "stork-fish-stone axe" belonging to the Miaodigou cultural phase was found in an adult funeral urn unearthed from the Yancun site of Linru, Henen Province, which was interpreted as a picture of weapons used in the war (Qian, 2009).

On the whole, in spite of the preservation problems and ambiguous interpretation of the archaeological evidence, various kinds of archaeological evidence found in major Neolithic regions of China indicated that during the middle Holocene 6.0–5.0 cal ka BP, the occurrence frequency of the inter-group conflicts and wars obviously increased, which supports the theory that war is the main driving force of complex society evolution (Carneiro, 1970).

4. Climate event around 5.5 cal ka BP

China is one of the few countries with various types of paleoclimatic archives, which provide abundant evidence for identifying and understanding the 5.5 cal ka BP climate event. In the southern Tibetan Plateau, a stalagmite δ^{18}O record with 5-year resolution from the Tianmen Cave revealed an obvious climate anomaly during 5.4–5.2 cal ka BP, indicating weakening of Indian summer monsoon (Cai et al., 2012) (Figure 1g). Such climate event agrees with a synthesis study of sediment grain size, carbonate content and TOC from the Qinghai Lake, which collectively revealed a summer monsoon weakening around 5.3 cal ka BP (An et al., 2012). In the northeastern Tibetan Plateau, the Dunde ice core δ^{18}O revealed three sharp cooling events during 6.0–5.0 cal ka BP (Thompson et al., 1989) (Figure 1c). In the eastern Tibetan Plateau, a well-dated and highly-resolved δ^{13}C record of the *C. mulieensis* remains cellulose from the Hongyuan peat revealed a marked drought period between 5.6 and 5.2 cal ka BP (Hong et al., 2003) (Figure 1d), whereas the δ^{13}C of mixed plant cellulose showed a sharp increase after 5.5 cal ka BP, indicating termination of Holocene Climate Optimum (Figure 2c). Similar climate transition was recorded by pollen record from the Qinghai Lake in the northeastern Tibetan Plateau, which indicated that tree pollen percentage decreased abruptly after 5.5 cal ka BP (Shen et al., 2005) (Figure 2d).

Farther to the east in the East Asian monsoon marginal areas of North China, several paleoclimatic records all indicated that the Holocene Climate Optimum terminated at about 5.5 cal ka BP. The pollen record from Bayanchagan Lake documented that vegetation changed from steppe woodland to steppe after 5.5 cal ka BP (Jiang et al., 2006) (Figure 2e). The water level reconstruction from the Dali Lake in Inner Mongolia revealed that lake-level lowered by about 30 m at 5.5 cal ka BP and never recovered to its previous level since then (Goldsmith et al., 2017). In the northeast margin of Loess Plateau, a 20-year sampling resolution pollen-based quantitative precipitation reconstruction from Lake Gonghai recorded a climate transition to relative drier period after 5.5 cal ka BP (Chen et al., 2015) (Figure 2b).

In the west region of Loess Plateau, a stalagmite δ^{18}O record with 8-year resolution from Wanxiang Cave revealed an extremely weakened summer monsoon event around 5.4 cal ka BP (Bai et al., 2017). In the Nanyang area of central China, another 4–5 years resolution stalagmite δ^{18}O record revealed two weakening monsoon events at 5.8–5.7 cal ka BP and 5.3–5.1 cal ka BP, respectively (Ren et al., 2006). In the Guanzhong Basin, a synthesis study demonstrated that paleosol accumulation was interrupted by the loess deposition during 6.0–5.0 cal ka BP (Huang et al., 2000).

In northeastern China, a Hani peat record revealed a broad increase in plant cellulose δ^{13}C during 5.8–5.0 cal ka BP, indicating that a dry climate conditions prevailed. Pollen record from the nearby Jinchuan peat showed an increase in coniferous tree pollen at the expense of temperate broad-leaved tree pollen at 5.5 cal ka BP in response to a colder climate (Jiang et al., 2008). A highly-resolved stalagmite δ^{18}O from the Nuanhuo Cave in Liaoning Province portrayed a well-defined reduction in monsoon intensity after 5.5 cal ka BP, which also marked the end of Holocene Climate Optimum (Wu et al., 2011). In the northern Daxinganling region, a pollen record from a peat deposition in the Huola Basin indicated that temperature was significantly dropped during 6.0–5.0 cal ka BP (Zhao et al., 2016).

To the south, in the middle reaches of Yangtze River, three stalagmite δ^{18}O records from the Lianhua Cave in Longshan County (Zhang et al., 2013), the Heshang Cave in Qingjiang, Hunan Province (Hu et al., 2008; Figure 2h), and the Sanbao Cave in Shennonjia, Hubei Province (Dong et al., 2010; Figure 2g) collectively revealed that the summer monsoon started to weaken after 5.5 cal ka BP, indicating the termination of Holocene Climate Optimum in this region.

In Southwest China, a stalagmite δ^{18}O record from the Dongge Cave in Guizhou Province (Figure 1i) showed a pronounced decrease in summer monsoonal rainfall around 5.5 cal ka BP (Wang et al., 2005); similar climate transition indicating termination of Holocene Climate Optimum was revealed by another stalagmite δ^{18}O record from the same cave (Figure 2i). In addition, this stalagmite δ^{18}O record also documented an obvious monsoon weakening event during 5.6–5.2 cal ka BP (Dykoski et al., 2005). In South China,

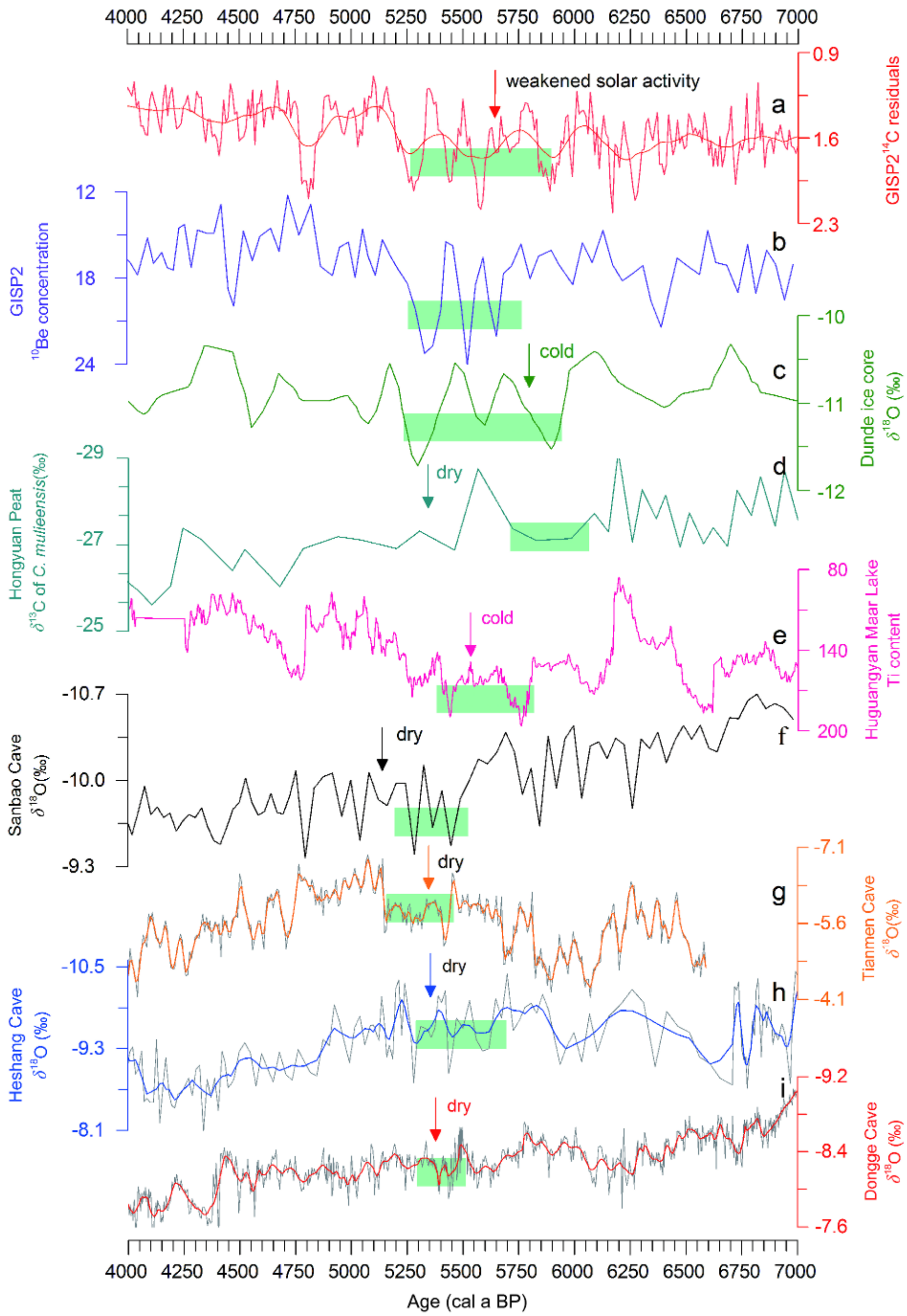

Figure 1 A comparison between climatic records and solar activity around 5.5 cal ka BP in China. (a) ^{14}C content in GISP2 ice core (Stuiver et al., 1998); (b) ^{10}Be concentration in GISP2 ice core (Steinhilber et al., 2009); (c) $\delta^{18}O$ record from Dunde ice core (Thompson et al., 1989); (d) $\delta^{13}C$ of the *C. mulieensis* for Hongyuan Peat (Hong et al., 2003); (e) Ti content for Huguangyan Maar Lake (Yancheva et al., 2007); (f) stalagmite $\delta^{18}O$ record for Sanbao Cave (Dong et al., 2010); (g) stalagmite $\delta^{18}O$ record for Tianmen Cave (Cai et al., 2012); (h) stalagmite $\delta^{18}O$ record for Heshang Cave (Hu et al., 2008); (i) stalagmite $\delta^{18}O$ record for Dongge Cave (Wang et al., 2005). The shade indicate time period of the 5.5 cal ka BP event.

nearly annual Ti record from Huguangran Maar Lake in Guangdong Province (Figure 1e) showed that the winter monsoon was intensified and rainfall was reduced during 5.9–5.2 cal ka BP (Yancheva et al., 2007), whereas another multi-proxy study of the same lake sediment indicated that the Holocene Climate Optimum ended around 6.2 cal ka BP (Wang et al., 2016).

Generally, quantitative climate reconstructions spanning 6.0–5.0 cal ka BP are sparse, which, however, did record the 5.5 cal ka BP event. For example, a quantitative climate reconstruction based on pollen record from the Daihai Lake indicated a July cooling of roughly 4°C during 5.8–5.6 cal ka BP as compared to the previous 7.4–6.0 cal ka BP period and a 1°C decrease in annual temperature relative to that at present (Xu et al., 2003). The occurrence of buried ice wedge in Diaojiaohaizi Lake in the Inner Mongolia indicated that

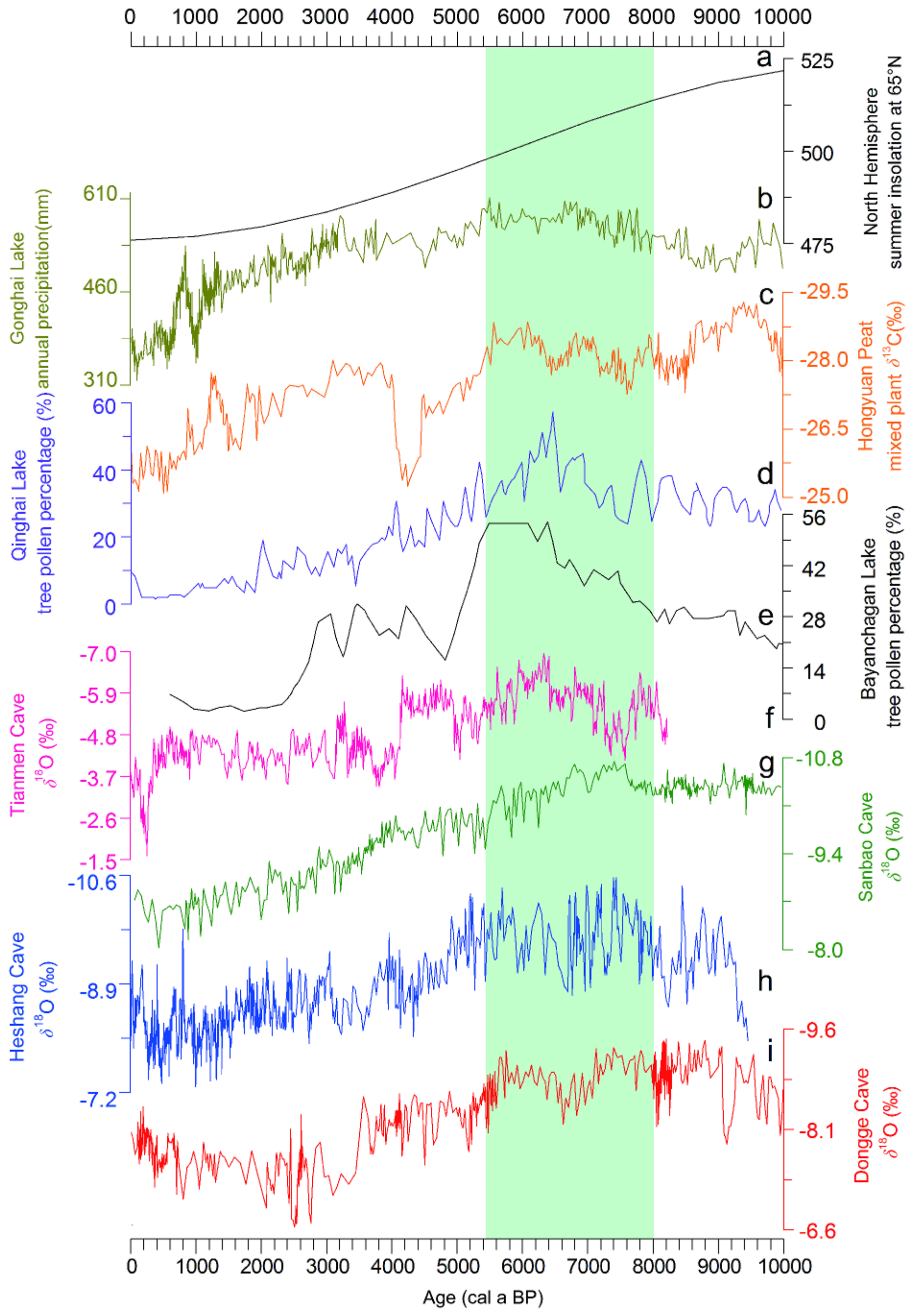

Figure 2 A comparison of lake records, stalagmites δ^{18}O records from China and summer insolation. (a) Summer insolation at 65°N (Berger and Loutre, 1991); (b) annual precipitation reconstruction for Gonghai Lake (Chen et al., 2015); (c) δ^{13}C of mixed plant cellulose for Hongyuan Peat (Hong et al., 2003); (d) tree pollen percentages for Qinghai Lake (Shen et al., 2005); (e) tree pollen percentages for Bayanchagan Lake (Jiang et al., 2006); (f) stalagmites δ^{18}O record for Tianmen Cave (Cai et al., 2012); (g) stalagmites δ^{18}O record for Sanbao Cave (Dong et al., 2010); (h) stalagmites δ^{18}O record for Heshang Cave (Hu et al., 2008); (i) stalagmites δ^{18}O record for Dongge Cave (Wang et al., 2005). The shade indicates the timing of Holocene Thermal Maximum and the climatic transition around 5.5 cal ka BP.

the annual mean temperature during 6.0–5.8 cal ka BP was at least 3°C lower than that at present (Zhang et al., 1997). Pollen from three lakes in the lower reaches of Yangtze River indicated roughly 1°C drop in annual temperature at 5.5–5.0 cal ka BP relative to today (Li et al., 2017).

In summary, numerous well-dated and highly-resolved paleoclimatic records across much of China showed pronounced climatic anomalies during 6.0–5.0 cal ka BP, some of which also marked the termination of Holocene Climate Optimum.

Paleoclimate records from other regions of the world also documented similar climate change during 6.0–5.0 cal ka BP period. Large-scale glacial advances started in both northern and southern hemisphere at 5.5 cal ka BP, indicating the

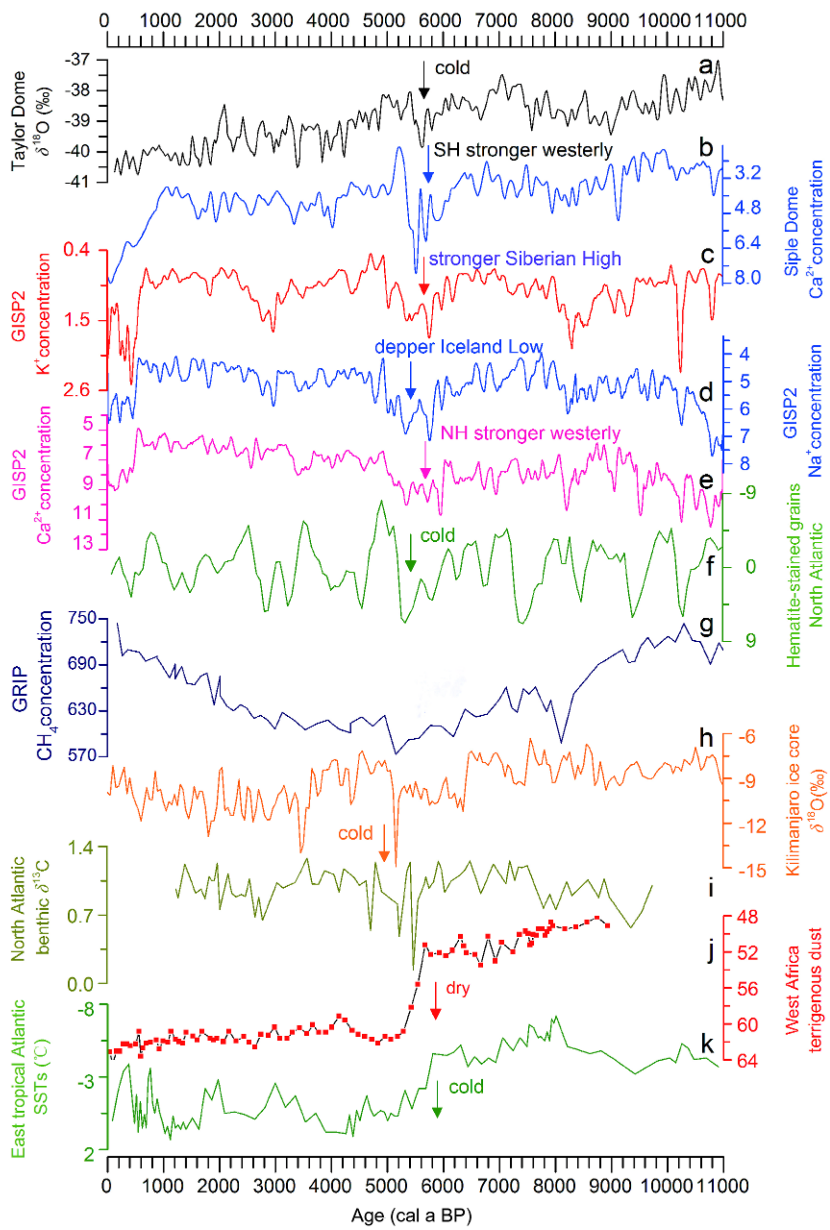

Figure 3 Paleoclimatic records from other regions of the world. (a) $\delta^{18}O$ record for Taylor Dome (Steig et al., 2000); (b) Ca^{2+} contentration for Siple Dome (Yan et al., 2005); (c) K^{+} contentration for GISP2 ice core (Mayewski et al., 1997); (d) Na^{+} contentration for GISP2 ice core(Mayewski et al., 1997); (e) Ca^{2+} contentration for GISP2 ice core (Mayewski et al., 1997); (f) Hematite-stained grains for North Atlantic(Bond et al., 1997); (g) CH_4 contentration for GRIP ice core (Blunier et al., 1995); (h) $\delta^{18}O$ for Kilimanjaro ice core (Thompson et al., 2002); (i) benthic $\delta^{13}C$ for North Atlantic (Oppo et al., 2003); (j) terrigenous dust record for West Africa (deMenocal et al., 2000b); (k) SSTs record for East tropical Atlantic (deMenocal et al., 2000a).

initiation of Holocene Neoglaciation (Denton and Karlén, 1973). The North Atlantic Ocean sediment core revealed that one of most remarkable ice raft events occurred during 6.0–5.0 cal ka BP (Figure 3f), which has been known as the Bond Event 4 (Bond et al., 1997). In the same North Atlantic, a sea sediment record documented a pronounced decrease in benthic $\delta^{13}C$ values (Figure 3i) during 6.0–5.0 cal ka BP, indicating the largest reductions in thermohaline circulation during the Holocene (Oppo et al., 2003). Precisely-dated and highly-resolved GISP2 potassium, sodium, and calcium maxima records (Figure 3c–e) indicated an intensified Siberia high pressure, weakened Iceland low pressure, and strengthened Westerlies during 6.0–5.0 cal ka BP, respectively (Mayewski et al., 1997). The Antarctic Siple Dome ice-core calcium maxima (Figure 3b) showed that the southern hemisphere westerlies was also strengthened (Yan et al., 2005), and a trough in the Taylor Dome $\delta^{18}O$ curve (Figure 3a) indicated a discerable drop in temperature (Steig et al., 2000). The GRIP methane concentration reduced to its lowest value at 5.2 cal ka BP during Holocene, which was thought to be indicative of aridity at low latitudes (Blunier et al., 1995; Figure 3g).

In tropical East African, reduced rainfall was inferred from a dramatic increase in dust content and a sharp depletion in δ^{18}O (Figure 3h) at 5.2 cal ka BP from the Kilimanjaro ice core record (Figure 3h) (Thompson et al., 2002). Both the terrigeneous dust content (Figure 3j) (deMenocal et al., 2000b) and the sea surface temperature record from West African (Figure 3k) (deMenocal et al., 2000a) all showed an abrupt climatic shift around 5.5 cal ka BP, indicating the termination of African Humid period. This abrupt climate change was also called the Sahara Drought event (deMenocal et al., 2000b). In the Cariaco basin, the low Ti concentration after 5.5 cal ka BP reflected increased aridity, marking the end of Holocene Climate Optimum (Haug et al., 2001). A synthesis study indicated that ENSO-dominated climate became active around 5.5 cal ka BP and affected broad regions of the Pacific, including the west United States, Australia, New Zealand, and the northeastern part of Asia (Sandweiss et al., 1999). Examination of 44 globally distributed paleoclimate records, including vegetation, glaciers, Alpine treeline, permafrost, high latitude treeline, sea temperature, polar ice caps, and tropical ice cores, collectively revealed a pronounced climate change event at 5.5 cal ka BP (Magny and Haas, 2004).

In summary, available paleoclimatic records clearly showed a pronounced climate anomaly during 6.0–5.0 cal ka BP within dating error, which also marked the termination of the Holocene Climate Optimum (Haug et al., 2001; deMenocal et al., 2000b) and the initiation of Holocene Neoglaciation in many regions around the globe (Denton and Karlén, 1973; Steig et al., 1998). Such 5.5 cal ka BP climatic event also showed two distinct characteristics: first, it occurred across broad regions, and most probably on a global scale; second, it occurred abruptly, and was probably accomplished within several decades (deMenocal et al., 2000b).

As regard to its causal mechanisms, several factors have been invoked to explain climate anomalies during 6.0–5.0 cal ka BP. The ^{14}C record showed that solar activity fluctuated by three obvious time periods between 6.0 and 5.0 cal ka BP (Steinhilber et al., 2009; Stuiver et al., 1998). Such reduction in solar activity would directly led to the weakening of summer monsoon (Wang et al., 2005). In addition, the weakened solar activity may cause an increase in North Atlantic drift ice (Bond et al., 2001) and a slowdown of North Atlantic meridional overturning circulation (AMOC) (Oppo et al., 2003). East Asian monsoon could quickly responded to these changes in the North Atlantic via atmospheric processes and resulted in its weakness (Liu et al., 2013). Reduction in solar activity can explain the climatic anomalies during 6.0–5.0 cal ka BP, but could not explain climate transition around 5.5 cal ka BP. Such shift was suggested to be related with the orbitally-driven insolation changes (deMenocal et al., 2000b; Figure 2a). Model studies indicate that the climate system has a non-linear response to the gradual decrease in insolation via a series of atmosphere-ocean-vegetation feedback mechanisms (deMenocal et al., 2000b). Once a threshold is crossed, abrupt climate change would occur, as is the case for the abrupt termination of African Humid period (deMenocal et al., 2000b). Therefore, the abrupt climate change during 6.0–5.0 cal ka BP was probably the combined effects of short-term solar activity and its superimposition on the long-term gradual orbital forcing changes (Magny and Haas, 2004).

5. The cause of war: Population-resource imbalance around 5.5 cal ka BP

Climate reconstruction indicates that 6.0–5.0 cal ka BP interval is a remarkable cooling period following the Holocene Climate Optimum. This cooling period corresponds approximately in timing with the escalation of conflicts and wars among human entities and the formation of complex societies in multiple areas of China within the dating error range, implying a possible causal link between them. We suggest that the joint actions of three factors, i.e., the 5.5 cal ka BP climate event, population growth, and circumscription, lead to population-resources imbalance, and then trigger the inter-group conflicts and wars.

5.1 The role of climate change

Climate change plays its role in triggering population-resource imbalance through two ways: firstly, it directly impacts the living and food production environment; secondly, it affects the regional resource carrying capacity. In the north of China, both foxtail millet (*Setaria italica*) and broomcorn millet (*Panicum miliaceum*) had been extensively and intensively cultivated during the middle Holocene. These two crops are very sensitive to temperature and precipitation variations, especially to frost damage. Drop in temperature can reduce the accumulated temperature and length of frost-free interval, and increase the occurrence frequency and magnitude of extreme cold events, which all could exert adverse impacts on the growth of millet crops (Fang and Sun, 1998; Zhang et al., 2016). In the south, the frequency in the occurrence of flood disasters may increase during the 5.5 cal ka BP cooling period, which could impact human living and rice cultivating environment and rice yields (Wu and Liu, 2004).

It should be noted that the impact of extreme climatic events during the cooling period should not be neglected. A large quantity of historical records show that the impact of long-term climate change is probably the result of accumulated effects of short-term climatic event impacts during abnormal climate period (De Vries, 1980). During cooling period, the frequency of and magnitude of extreme cold events increases, which can affect the strength, duration, and locations of frontal monsoon rainfall belt (Wu and Liu, 2004), and further lead to an increase in the occurrence of abnormal rainfall in some areas, thus adversely affecting the human living and crop production environment and its yields. This is verified by abundant Historical documents which record an apparent increase in drought and flood disasters during cooling period (Zheng and Feng, 1986). The cooling amplitude of the 5.5 cal ka BP climate event is large, extreme cold events likely increase, leading to frequent occurrence of meteorological disastrous.

5.2 The role of population growth

Population growth plays two important roles in the occurrence of between-group conflicts: first, it provides the necessary condition for the climate change to cause population-resources imbalance; second, it lead to the formation of demographic circumscription.

5.2.1 Providing the necessary condition for population-resource imbalance

The degree to which climate change impacts on population-resource imbalance is related not only to the nature of climate change itself, but also to the level of population growth approaching the regional resource capacity. If population size is much lower than resource carrying capacity, the impact of climate change is slight; conversely, if population size is close to the land carrying capacity, even a small climate change can lead to a severe population-resource imbalance.

Previous studies showed that population increased rapidly in many regions of China during the Holocene Climate Optimum (8.0–6.0 cal ka BP) (e.g. Wang et al., 2014). Nevertheless the present archaeological evidence could not verify whether or not the population level is close to the resources capacity at that time. We need to resort to demographic theory to understand the nature of population behavior and thereby gain insight into the then population size. As any other animal species, human being owns the capacity of fast population growth (Wood, 1998). Generally, the prehistoric population growth rate seems rather low; however, such near-zero growth rate is likely the results of long-term averaging between periods of relatively rapid local population growth and population crashes caused by density-dependent and density-independent factor, such as climate change, famine, and inter-group conflicts and wars (Boone, 2002).

Numerous studies show that even though preindustrial population growth rate is relatively low, its exponentially-growing population under conditions without resource limitation would approach the local resource capacity within a relatively short time period (Cowgill, 1975; Wood, 1998). As far as the population growth rate is concerned, the average annual growth rate of Kung people, living in a relatively marginal foraging environment of southern Africa, is 7‰ (Boone, 2002), while the a tropical foraging group, the Ache of Paraguay, could reach a pre-contact average annual growth rate of 25‰ in a short time period (Hill and Hurtado, 1996).

Richerson et al. (2001) systemically studied the effect of such an exponential population growth. They assumed that a maximum population pressure at a given area is 100% when the population level is close to the land carrying capacity, and the population pressure at the beginning of its growth is only 1% of its maximum. Population unconstrained by resource limitation with an annual growth rate about 10‰ will grow and reach to its 99% of the maximum population pressure in merely 920 years. Similar conjectures could also be used to understand the effects of this exponential population growth. Hassan (1979) speculated that global population was about 9 million at the end of the Pleistocene, whereas Tallavaara et al. (2015) showed that the population of Europe was 0.41 million around 13 cal ka BP at the end of Last Glacial. It is thus conservatively to assume one million global populations around 11 ka BP at the onset of Holocene. With a 4‰ annual population growth rate, the population would reach 9.7 billion after 2200 years; with a 10‰ average growth rate, the global population would grow up to 20.9 billion within 1000 years, a population size far outnumbers that at present.

Although technological progress can alleviate the population-resource pressure, such alleviation is only temporary. Because population grows geometrically, while the resource supply brought about by technological progress grows arithmetically. On a time scale of more than several hundred years, no matter how technology advances, population growth unconstrained by resource limitations will grow rapidly and approach the local resource carrying capacity (Wood, 1998; Richerson et al., 2001).

In China both millet and rice agriculture were originated more than 10000 years ago, fully-settled agrarian society had been established abroad 8.0 cal ka BP, and agriculture intensified apparently during 7.0–6.0 cal ka BP (Dong et al., 2016, 2017). During the subsequent favorable climate period, especially the Holocene Climate Optimum during 7.0–6.0 cal ka BP, population would increase rapidly, and approach the regional resource carrying capacity before 5.5 cal ka BP.

5.2.2 Formation of circumscription

In times of resource stress and resulted intergroup conflicts, the best adaptable strategy for the disadvantaged groups is to migrate to other areas where land resources are available.

Circumscription refers to restricted conditions that can prevent the disadvantaged people to emigrate to avoid being controlled and losing their social-political status. Carneiro (1970) proposed two types of circumscription. One is geographical circumscription. It means that some human groups are surrounded by lands with lean resources such as desert and grassland, or by obstacles which can hamper large-scale human migration, such as dense forest, mountains, and large water bodies such as lakes, rivers, and seas. The second is social circumscription, which usually means that a certain human group is surrounded by densely populated groups. In the major Neolithic cultural regions of China, except in the fragile environmental areas in the north, northwest, and northeast of China, where certain geographic limitations works as a result of the 5.5 cal ka BP climate deterioration, obvious geographical circumscription is generally non-existent. However, social circumscription exists and works. After several thousand years' growth, especially during the Holocene Climate Optimum in 8.0–6.0 cal ka BP, population would grow rapidly and approach quickly the regional land carrying capacity, which is enough to form demographic circumscriptions. In addition, people had evolved into fully-settled agrarian societies at that time, which increased the cost of migration and enhanced the strength of circumscription. Such demographically-caused circumscription contributed to the emergence of population-resource imbalance caused by climate deterioration around 5.5 cal ka BP by preventing population migrating to other areas.

6. Population-resource imbalance and society evolution

Plentiful ethnological and archaeological studies show that, like other primates, human generally incline to a subordinate relationship between leaders and common followers under the hierarchical reign (Boehm, 1999). Such hierarchical rule depends on the physical capacity of individuals. However, with the increasing use of lethal weapons made of wood and stone, the cost for common members to punish the selfish and aggressive leaders is greatly lowered, making it impossible to control others by pure physical prowess (Gintis et al., 2015). Guided by the egalitarian ethos, the common members join forces to form a strong community, and establish a social leveling mechanism aimed at preventing the hierarchical formation, which is the suggested reverse dominance hierarchy (Boehm, 1999). They collectively employ the social leveling mechanisms to monitor, oppose, and punish (including private talking, public voicing, criticizing, mocking, isolating, dismissing, abandoning, and even killing, etc.) those persons who abuse the power and threaten the autonomy and equal rights of other tribal members, to make sure that the decisions of the leaders are basically accordant with their basic interests, and finally guarantee that all members can equally get the natural and social resources, corresponding status, and decision-making autonomy (Boehm, 1999).

Therefore, to seek a permanent institutionalized leadership, besides possessing appropriate skills and abilities for effective leadership, aspiring leaders must overcome the powerful leveling mechanisms whose very design is to maintain an egalitarian ethos (Kantner, 2009). If leaders can demonstrate to their followers that they will benefit from his leadership, the leveling force of prevailing egalitarian ethos will be weakened, the monitoring of ordinary members on the behavior of leaders may be relaxed, then the leader will have the opportunity to maintain even expand his power, till it is legalized and institutionalized (Kantner, 2009). Under normal circumstances, the future social or natural changes can be predicted, the established cultural mechanisms can guide decision making, and social leveling mechanisms can maintain an egalitarian ethos, thus the centralized leadership and decision-making are not needed. In contrast, in times of crisis, collective or *ad hoc* decision-making would put the group survival in great danger, while centralized power and decision-making are vital for the success of collective action (Kantner, 2009), especially in inter-group conflicts or wars, in which centralized decision making would benefit all the members of whole group (Carneiro, 1970). In such conditions, the leveling forces would be weakened, and the aspiring or ambitious leaders could overcome the restriction brought by egalitarianism and thus establish their prestige, authority, and power (Kantner, 2009). If the crisis period is so short that the leadership has not been legalized and institutionalized, the leadership would be temporary. After the crisis, the leadership becomes useless and the society would be reversed into egalitarian society (Kantner, 2009). Therefore, the emergence of leadership is usually limited only to particular circumstance and time period. Kantner (2009) suggested three contexts, i.e., demographic shift, climatic change, and social-political change, which contribute to the formation of leadership, and considered demographic change as the key factor in the emergence of permanent leadership. However, Kantner's hypothesis (2009) cannot explain the fact that why nonegalitarian society emerged simultaneously around 5.5 cal ka BP in a number of regions around the world, including China?

In the case of social evolution during the middle Holocene in China, we suggest that in demographically circumscribed conditions, the 5.5 cal ka BP climate event acted on a population density level close to the resource carrying capacity, and caused population-resource imbalance, which further triggered inter-group conflicts and wars. Such natural and social context provided an opportunity for those power-thirsty and status-pursuing agents to become the leaders, which led to the initial emergence of unequal society.

However, because of ubiquitous existence of social leveling mechanisms, even some agents can acquire temporally the leadership; they need some measures or additional mechanisms to maintain their authority or power (Kantner, 2009). Some scholars suggested that leaders can strengthen their control on the common members by controlling the economic, military, and ideological power, and hence gain their permanent and institutionalized leadership (Earle, 1999); while others (e.g. Kantner, 2009) emphasized the role of other factors, especially population growth, which can weaken the monitoring force on the leaders' behavior by the ordinary tribal members. However, all these hypotheses could not satisfactorily explain the onset timing of unequal society in China. We suggest that the recurrent impacts of the increased extreme climate events during 6.0–5.0 cal ka BP cold period are vitally important. The decrease in average temperature in 6.0–5.0 cal ka BP caused an increase in the occurrence frequency of extreme cold events, which resulted in frequent occurrence of population-resource imbalance, and further increased the frequency of inter-group conflicts and wars. Such recurrent social crisis provided a long-period opportunity for the agents to pursue their power. It contributed to weaken the restriction of social leveling mechanisms, increase the feasibility of legalization and institutionalization of their leadership, which led to a permanent institutionalized unequal society.

Another social factor i.e. the group selection in a competitive environment is also favorable to the maintenance and persistence of initial institutionalized inequality society. The 5.5 cal ka BP climate event might lead to a situation of intergroup competition at its beginning. In such circumstance the centralized decision-making by autocratic leadership in unequal context is more advantageous than the collective decision-making under egalitarian conditions (Kantner, 2009), thus the leadership would be needed. However, once the crisis is eliminated while the permanent inequality system have not been fully established yet, the inter-individual competition within a group may overwhelm the group selection force, likely leading to a reverse society transition from inequality to equality. Therefore, although inter-group competition is conducive to maintaining inequality, it also depends on context. In this case, an increase in extreme climate event during the 6.0–5.0 cal ka BP cold period played an important role in the maintenance and persistence of inequality.

7. Conclusion

Drawing on agency theory, we put forward a testable hypothesis for the emergence of complex societies in a number of areas in China around 5.5 cal ka BP. Our hypothesis is different from the previous understandings in the following three aspects. Firstly, previous studies often emphasized the resources pressure induced only by climate change, while we put emphasis on the jointed action of three factors, including climate change, population growth, and circumscription to cause the regional population-resources imbalance; secondly, we emphasize the role of climate extremes, and suggest that increase in the occurrence of extreme cooling events during 6.0–5.5 cal ka BP cold period would lead to recurrent or even persistent population-resources imbalance, which further trigger long-lasting conflicts and wars. Such intergroup competition would loosen the restriction of leveling mechanism, provide the opportunity for some agents to break the constrains of social leveling mechanisms and become permanent institutionalized leaders, which finally contribute to the establishment of permanent institutionalized inequality around 5.5 cal ka BP; thirdly, we establish the causal link between climate change and complex society evolution from the perspective of agency theory, which avoid the simple environmental determinism and help to understand the dynamic mechanisms behind the emergence of complex societies. Compared with previous hypotheses, our hypothesis can not only explain well the process and dynamic cause of the initial emergence and persistence of complex society in China, but also two phenomena which other theories fail to explain: first, why did the Chinese complex society emerge at about 5.5 cal ka BP but not at other times; second, why did human groups in different regions evolve into the complex society at nearly the same time period.

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