Abrupt climate change and collapse of ancient civilizations at 2200BC—2000BC*

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Abstract Plentiful evidence of historical, archaeological and palaeoclimatic studies proved that an abrupt change from wetter to drier climate occurred over the Nile Valley, the Mesopotamia, the Indus Valley and Huanghe River Valley at 2200BC—2000BC. The abrupt change was developed based on the general lowering of temperature in the middle latitudes, and was a strong cold event since the beginning of the Megathermal (8.5—3.0 kaBP). Collapse of Nile civilization appeared at the First Intermediate Period (2181BC—2040BC). Civilization of Mesopotamia began collapse following the disintegration of Akkadian Empire. This process lasted to the foundation of Babylon Kingdom from 2200BC to 1900BC. Indus civilization abruptly fell off at 1800BC. A widespread alternation of archaeological cultures happened in China at ca. 2000BC except only in its central part. Longsheng culture was replaced by the Erlitou culture, which is now acknowledged in China as Xia Culture. Foundation of Xia Dynasty at 2070BC opened a new chapter in the development of Chinese civilization. Studies indicated that abrupt climate change may be caused by the weakening of the Thermohaline Circulation (THC).

Keywords: 2200BC—2000BC, abrupt climate change, collapse of ancient civilization.

Suzuki[1] reviewed the palaeoclimatic records on the abrupt climate change at 50 locations worldwide, and indicated that: (1) temperature lowered at 3.5 kaBP, (2) lowering of temperature caused increasing of aridity in lower latitudes, and (3) cooling and dryness accelerated the collapse of ancient civilization. It is worth to note that: (1) it was really an abrupt climate change with 3 ℃ lowering of temperature, though the terminology was not used at that time. (2) The timing of 3.5 kaBP in Suzuki's study was referred to minimum in long-term temperature or precipitation curves, the process of temperature lowering and precipitation reduction lasted mainly from 3.8 kaBP to 3.5 kaBP. (3) ^{14}C year was used at that time, it should be 2200BC—1800BC considering the tree-ring correction.

Weiss et al.[2] indicated that the droughts in northeast Syria caused abandonment of agriculture area in Tell Leilan and the disintegration of the Akkadian Empire, by analyzing archaeological and soil-stratigraphic data at north Mesopotamia. An Advanced Research Workshop was held in Kemer, Turkey on 19—24 September 1994, at which the abrupt collapse of old world at 2200BC and its association to the climate change during 5.0—3.0 kaBP was discussed and a proceedings[3] was published. This workshop proved the overall occurrence of abrupt climate change from mid-East to the Indus Valley, and the collapse of ancient civizations over the Nile Valley, the Mesopotamia and Indus Valley following the increasing of aridity[4]. Later studies[5,6] supported the idea developed on the Workshop.

However, studies reported at the Workshop do not concern the abrupt climate change and the changes of ancient civilization over China. Recently, Wu and Liu[7] indicated that the cold event at 4.0 kaBP caused the collapse and finally the ending of Neolithic culture, and accelerated the development of the culture in the central China. Foundation of Xia Dynasty characterized the birth of Chinese civilization. Shi[8] has identified the occurrence of a cold event in China at 4.0 kaBP. Wang supported Shi's point of view[9], and proposed that the cold event and the increasing of aridity may be caused by the weakening of the Thermohaline Circulation[10].

However, both the abrupt climate change at 4.0 kaBP and its impact on the collapse of ancient civilization are not fully understood though the topic was proposed more than ten years ago. Therefore, it is desirable to integrate the available historical, archaeological and palaeoclimatic data to identify the oc-

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currence of a cold event at 4.0 kaBP and to probe the possible impact of it on the collapse of ancient civilization around the world and over China. In this paper, the terminology of "kaBP" (thousand years before AD1950) is used when the ^{14}C year is applied; "BC" is used when the timing is corrected with tree-ring data, with a few exceptions indicated in the parenthesis when necessary.

1 Collapse of ancient Nile civilization and abrupt climate change

Thirty Dynasties were identified in the history of ancient Egypt. The First Dynasty began at ca. 3100BC. Three highest pyramids were built in the Fourth Dynasty (2613—2589BC). The First Intermediate Period (FIP) started since the Sixth Dynasty. However, there is discrepancy in the assessments on the absolute chronology of the FIP (Table 1). But most of the authors agreed that the period from Seventh to Eleventh Dynasty belongs to FIP (2181—2040BC). FIP lasted about one and a half of a century. However, what caused the split of the country which had been flourishing in the history? Historical records indicated that it might happen under the influence of rainfall reduction at the fountainhead of Nile. But, some one emphasized the impact of Asian refugee invasion. A peasant uprising accelerated the disintegration of the country and the collapse of the ancient civilization. The book of Yan[19] provided a series of water level record of Nile, which indicates that a 30% reduction of the Nile discharge occurred at 3000BC—2800BC. Of course, the social factor may also contribute to the formation of FIP.

Table 1. The First Intermediate Period

FIP	Cause	Dynasty	Authors
2181—2040BC	Uprising	7th—10th	Zhu, 1991[11]
2150—1986BC	Droughts	7th—11th	Rohl, 1995[12]
2213—2061BC	Droughts	7th—11th	Dersin, 1997[13]
2181—2040BC		7th—10th	Chen, 2001[14]
2181—2040BC		7th—10th	Jiang, 2001[15]
2181—1991BC		7th—11th	Vercoutter, et al., 2001[16]
2134—2040BC		7th—11th	Brown, 2002[17]
2181—2055BC	Droughts	7th—11th	Yan, 2002[18]

Because that 90% of the water during the overflowing of Nile came from the Blue Nile and Atbara River over the Ethiopian Highland, the lake level over the Ethiopia characterized the flood of Nile. The lake level was very high during the period of 9.0—6.0 kaBP with three peaks in 9.0 kaBP, 7.0 kaBP and 6.0 kaBP. It was lowered at 5.0 kaBP, and entered a period of low lake level during 4.0—3.5 kaBP[20]. Robert[21] also reported that there was a period of low lake level over the Ethiopia at 4.0—3.5 kaBP. Lake Turkana in north Kenya did undergo an abrupt change of lake level at 3.9 kaBP from open to closed basin status. Moreover, a lot of evidence shows the occurrence of minimum lake level at 2250BC—2200BC. Level of Lake Chad[20] in central part of north Africa and lakes in western Africa[21,22] was very low at 4.0kaBP. It suggests that the droughts at 2200BC covered a large area over the Africa, from western Africa to the Ethiopia Highland.

2 Collapse of ancient Mesopotamia civilization and abrupt climate change

Mesopotamia means the land between two rivers of Tigris and Euphrates. It is well known as a "Fertile crescent", one of places where the original civilization developed. The north of the Mesopotamia was called as Assyria, and the south called as Babylonia. The latter consisted of two parts: Akkad in the north and Sumer in the south. Akkadian Empire existed in between 2371BC—2191BC, which lasted a little less than two centuries. It was destroyed by the invasion of Guti. Then, Sumerians drove the Guti, and founded Ur III. However, the Ur III was destroyed quite soon, which lasted only less than a century from 2113BC to 2006BC. Later, the Amorites founded the Old Babylon Empire[23]. It was known that the King Hammurabi had been on the throne at 1792BC, which has been identified according to the record of Venus. Recently, it is suggested that the year of coronation should be 1848BC[24]. If the recalculation is true the chronology needs to be corrected. Anyhow, one can roughly say that the process from disintegration of Akkadian Empire to the establishment of Old Babylon Empire lasted about three centuries, from 2200BC to 1900BC, while a series of small empires existed over the Mesopotamia. Historians usually attribute the disintegration of Akkadian Empire to the invasion of Guti and environmental deterioration, they did not consider the influence of climate change.

Weiss[2] was the first scientist who proposed that the increasing of aridity is responsible for the disintegration of Akkadian Empire. Later great progress has been made in the studies of environmental archaeology. Study of Weiss[2] was limited in the Habur Plains of Syria, now, the study has extended from Taurus

and Zagros Mountains to the Palestine and the Gulf of Oman (Table 2). The evidence shown in Table 2 supported that a dry period persisted from 2200BC to 1900BC over the Mesopotamia. It is generally in agreement to the period when the Akkadian Empire disintegrated.

Table 2. Evidence of climate aridity at 4.2 ksBP

Place	Proxy data	Timing	Authors
Palestine	Level of Dead Sea	2200BC	Frumkin, et al. 1991[25]
Lake level	Pollen	2200—1950BC	van Zeist and Bottema, 1991[26]
Palestine	Speleothem isotope	2450—1900BC	Issar, et al. 1992[27]
Lake Van	Quartz content	4.2—4.0 kaBP	Lemcke and Sturm, 1997[28]
Syria	Glass shard	2200—1900BC	Courty, et al. 1997[29]
Gulf Oman	Dolomite dust	2300BC	deMenocal, 2001[30]

3 Collapse of ancient Indus civilization and abrupt climate change

Archaeologists discovered the Harappan civilization over Indus Valley during 19th and 20th centuries (Table 3), which lasted about 800 years (2600BC—1800BC). The ruins of the civilization extended from south Himalay and the coast of Arabian Sea to the present capital of India, New Delhi and the border between Pakistan and Iran, covered an area of 5.0×10^5 km^2. The ruins amount to ca. 250 locations, which are much more than that of the nearly contemporary Sumer civilization over the Mesopotamia. However, the Indus civilization abruptly declined at ca. 1800BC. Historians first attributed it to the invasion of Aryans. Then, it was proved that the invasion occurred at 1500BC, 300 years later than the decline of civilization. However, what had caused decline of the civilization over the Indus Valley? Zhao[33] and Xie[36] suggested that the deterioration of the environment may be responsible for the civilization decline. Rainfall had increased since 2400BC in south Asian sub-continent. But, increase of population and over-cultivation destroyed the vegetation, created soil erosion, and intensified the floods. There is archaeological evidence in Mohenjo Dario to confirm that the city was destroyed several times by the floods. A lot of authors emphasized the influence of droughts or earthquakes, and indicated that Indus had changed its course at 1900BC—2000BC (Table 3).

Table 3. Indus civilization (years of BC)

Beginning	Culmination	Ending	Cause of decline	Authors
2500	230	1700	Invasion	Thapar, 1990[31]
2400	2200—2000	1800	Soil erosion, droughts	Zhu, 1994[32]
2500		1700	Environmental deterioration	Zhao, 1999[33]
2600		1900	Floods, course change	Kenoyer, 2000[34]
2600		1800	Course change, floods	Brown, 2002[35]
2600		1900	Environmental deterioration	Xie, 2002[36]
2600	2000	1800	Course change	You and Chen, 2003[37]

Palaeoclimatic evidence proved that drying up of the lake in northwest India indicated the occurrence of prolonged dry period. Singh et al.[38], Bryson and Swain[39] investigated variation of lake level of Rajasthan to estimate monsoon rainfall in the Holocene, and the results proved a reduction of annual and monsoon rainfall at 3.7—3.5 kaBP. Around 3.7 kaBP the lake Lunkaransar became saline, shown by halophytes replacing Typha and other freshwater aquatic species in the pollen record, and dried up entirely within a few centuries. At the same time, dunes once more became mobile. Bentaleb et al.[40] investigated the variation of vegetation in the Holocene on the basis of marine cores taken from the inner shelf off Karwar near the mouth of the Kalinadi River. He found the decrease in tree pollen, particularly those of evergreen forests, reduction of mangrove, and increase of savanna grass pollen. Meanwhile, the stable carbon isotopic ratios of organic matter increased abruptly, indicating a higher contribution of organic matter of marine origin and consequently reduced input of terrestrial organic matter due to reduced flow of the Kalinadi River. All these changes point to a less humid climate and shorter rainy season in the region. Therefore, the prolonged aridity may at least partly responsible for the collapse of Happarian civilization.

4 Abrupt climate change and alternation of archaeological culture in China

Kong[41] examined the variation of vegetation in north China in the period of the Megathermal, 8.0—3.0 kaBP, and indicated that it is in accordance with the development of cultures during the Neolithic Age. It has been found by ^{14}C analysis of Qiu[42] that an overall alternation of archaeological culture occurred at 4.0 kaBP in Central, Shandong, Gansu-Qinghai and Inner-Mongolia-Northeast of China. Before 2000BC, China was being in the late of Neolithic Age, the civilization was characterized by Longshan culture, therefore, the time was called as Longshan Age. "*General History of China*"[43] indicated that there were five archaeological cultures during the Longshan Age, namely (Shandong) Longshan, Central Longshan, Qija, Liangzhu and Shijiahe cultures (Table 4). The first three were developed in lower, middle and upper reaches of the Huanghe River Valley, the later two appeared in the lower and middle reaches of the Changjiang River Valley. Shandong Longshan culture was replaced by Yueshi culture, but geographical scope of the latter diminished greatly in comparing with the former, the number of ruins reduced significantly[52]. The Qija, Liangzhu and Shijahe cultures declined. Moreover, Laohushan culture over Inner-Mongolia[47] and Hongshan culture in north China[53] also declined at ca. 2000BC. It infers that an overall alternation of archaeological cultures was happened over China.

What has caused the alternation of the archaeological cultures over China at ca. 2000BC? Wu and Liu[7] emphasized the impact of cold event. However, floods or droughts may also contribute to it (Table 5), though the floods may occur precede the droughts in north China. It is supported by the folklore about "struggle with flood" in Longshan Age. Natural disasters may also accelerate the war, which was happened between the chiefdoms[62]. The result of the war was the foundation of Xia Dynasty at 2070BC.[63]

Table 4. Archaeological cultures in Longshan Age

Culture	Area	Timing	Cause of decline
(Shandong) Longshan	Lower reaches of Huanghe River	2600—2000BC[43]	Flood[44]
Central Longshan	Middle reaches of Huanghe River	2600—2000BC[43]	
Qija	Upper reaches of Huanghe River	4200—3800BP[45]	Cold[45,46]
			Drought[47]
Liang Zhu	Lower reaches of Changjiang River	3300—2000BC[48]	Flood[44][49]
Shijiahe	Middle reaches of Changjiang River	2600—2000BC[50]	War[50]
			Environment deterioration[51]
			Flood[44]

Table 5. Evidence of abrupt climate change at 4.0kaBP in China (calendar year)

Region	Timing	Climate change	Authors
North China	4.2 kaBP	Severe cooling	Lü, 1991[54]
North China	3.5 kaBP(^{14}C year)	3 ℃ cooling	Zhang, 1997[55]
Inner-Mongolia	4.0 kaBP	Cold event	Tian, 2000[56]
Hebei	4.8—4.2 kaBP	Severe cooling	Jin, 2001[57]
North China	4.4—4.0 kaBP	Floods	Yang, 1993[58]
Delta of Changjiang	4.8—4.0 kaBP	Floods	Zhang and Jiang, 2003[59]
North China	4.0 kaBP	Droughts	Guo et al., 2000[60]
West Henan	4.0—3.5 kaBP	Droughts	Fang, 2000[61]

5 Discussion

Aforementioned evidence proved that an overall abrupt climate change occurred in Nile Valley, Mesopotamia, Indus Valley and Huanghe River Valley at 2200BC—2000BC, and it influenced the collapse of ancient civilization in the old world and alternations of archaeological cultures in China. However, some issues should be studied further.

5.1 Regional characteristics of abrupt climate change

Climate characteristic and mechanism differs each other in Nile Valley, Mesopotamia and Indus Valley, though there is evidence supporting the simultaneousness of collapse of ancient civilization in these three regions. Flood over the Mesopotamia depends on the water source in Taurus Mountains,

where predominated Mediterranean climate, rainfall concentrated in winter months. The discharge of Euphrates at Keban in Turkey remains about 300 m^3/s from July to February of next year, but it culminates at April with a peak of 2000 m^3/s. Discharge of Euphrates relates to melting of snow, so the maximum discharge appears in April to May. Of the 90% discharge of Nile comes from the flow of Blue Nile and Atbara River, which depends on the summer monsoon rainfall in the Headwater over the Ethiopian Highland, where rainfall concentrates in June to September. Therefore, the Nile is in flood from July to October, which differs greatly to that in the Mesopotamia. It suggests that characteristic and mechanism of abrupt climate change should be studied further from region to region.

5.2 Causes of abrupt climate change

Suzuki[1] had attributed the decline of Minoan civilization over the Mediterranean to the enormous volcanic eruption in the Santorini Islands of the Aegean Sea at 3.5 ksBP. He indicated that widespread reduction of temperature caused by the eruption may directly bring to the collapse of other ancient civilizations. Starkel[64] found the dependence of cold events in the Holocene; 5.1 kaBP, 4.6 kaBP and 3.1 kaBP on the volcanic eruptions. Hsu[6] interpreted the occurrence of cold event with solar activity. It has also been argued that ENSO is responsible for the occurrence of cold events.[65,66]

Many authors acknowledged that the weakening of the Thermohaline Circulation (THC) may cause the abrupt climate change.[67,68] However, the influence of weakening of THC on the climate has not been well examined. Recently, Wang et al.[10] demonstrated by using of GCM modeling that drought would occur in Turkey and Ethiopia if the THC weakened. It strongly suggests that the weakening of THC may cause the abrupt climate change.

Cullen and deMenocal[69] demonstrated that North Atlantic Oscillation (NAO) is one of the main mechanisms related to the reduction of rainfall over the Turkey in winter, because cyclone path turns to the northeast to the Europe, then the rainfall over the Turkey decreases in the positive phase of NAO. On the contrary, cyclone path orients to the east, brings about plentiful rainfall over the Turkey in negative phase of NAO. It is in agreement with the study of Wang et al., for NAO is in positive phase when THC weakens. Anyhow, the mechanism and causes of abrupt climate change need to be studied.

5.3 Abrupt climate change and evolution of ancient civilization

Suzuki[1] has indicated that the cold event at 5.0 kaBP and the droughts may accelerate the beginning of ancient civilization. Wu and Liu[70] studied the influence of the cold event at 5.5 kaBP (calendar year) on the development of three ancient civilization in the old world and evolution of civilization in China. The cold event at 8.2 kaBP may promote the development of agriculture and animal husbandry[71]. Therefore, all of the three cold events at 8.2 kaBP, 5.5 kaBP and 4.0 kaBP are important for the evolution of ancient civilization.

Finally, it is worth to note that time resolution of the palaeoclimatic data is not big enough, technology of timing is far from accuracy, though sometimes the correction according to tree-ring data is used. Therefore, uncertainties remain in the studies. However, with more and more historical, archaeological and palaeoclimatic evidence accumulated, the abrupt climate change is considered to be a very important factor influencing the evolution of ancient civilization. It encourages the further study in the future.

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