Front. Earth Sci. 2016, 10(4): 669–682
DOI 10.1007/s11707-015-0575-7

RESEARCH ARTICLE

Emergence of ancient cities in relation to geopolitical circumstances and climate change during late Holocene in northeastern Tibetan Plateau, China

Guanghui DONG (✉)[1], Honggao LIU[1,2], Yishi YANG[1], Ying YANG[1], Aifeng ZHOU[1], Zhongxin WANG[3], Xiaoyan REN[3], Fahu CHEN[1]

1 Key Laboratory of Western China's Environmental Systems (Ministry of Education), College of Earth and Environmental Sciences, Lanzhou University, Lanzhou 730000, China
2 College of Agronomy and Biotechnology, Yunnan Agricultural University, Kunming 650201, China
3 Qinghai Provincial Institute of Cultural Relics and Archaeology, Xining 810007, China

Abstract The study of the history of human activities in ancient cities has provided valuable evidences for understanding the evolution of human-land relations during the late Holocene. Numerous ancient cities were discovered through archaeological surveys of the east Qinghai Province, located on the northeastern border of the Tibetan Plateau, China; however , the mystery of when or why these cities were built remains unsolved. As recorded in this paper, we sampled reliable dating materials from 47 ancient cities in the area, determined their ages by radiocarbon dating, and compared the dating results with historical documents and high resolution paleoclimate records to explore the influencing factors for the development of these ancient cities. The 54 radiocarbon dates indicated that most of these cities were built or repaired during the Han Dynasty (202 BC−AD 220), Tang Dynasty (AD 618−AD 907), the Five Dynasties and Ten Kingdoms period (AD 907−AD 960), the Song dynasty (AD 960−AD 1279), and the Ming Dynasty (AD 1368−AD 1644). The radiocarbon dates correspond well with historical records of the area. Our work suggests the ancient cities in east Qinghai Province were likely built primarily for military defense, and may have also have been affected by climate change.

Keywords radiocarbon dating, ancient city, historic records, war, climate change

Received September 24, 2015; accepted December 15, 2015

E-mail: ghdong@lzu.edu.cn

1 Introduction

When and how prehistoric humans colonized the Tibetan Plateau has been intensively discussed during the last ten years (Brantingham and Gao, 2006; Zhao et al., 2009; Aldenderfer, 2011; Brantingham et al., 2013; Dong et al., 2013; Rhode et al., 2014; Chen et al., 2015; d'Alpoim Guedes et al., 2015). Recent research indicated that prehistoric humans had extensively and permanently settled on the high areas of the Tibetan Plateau since 3600 BP, which was primarily promoted by agricultural development and diffusion across Eurasia during late prehistoric times (Chen et al., 2015). However, human settlement and its influencing factors during the historic period in the high Plateau remain enigmatic. The absence of reliable dates from historic sites and documents analysis, and their comparison with high resolution paleoclimatic records, obstruct our understanding of the human-environment relationship in the Tibetan Plateau during the past two millennia.

Vast amounts of information have been recorded about historical cultures in ancient cities (such as politics, the military, religion, economics, etc.), and are valuable for studying the human-land relationship during late Holocene, especially in arid areas (Gao et al., 2013). Numerous ancient cities were discovered through archaeological surveys in east Qinghai Province, China, located on the northeastern border of the Tibetan Plateau (Bureau of National Cultural Relics, 1996). However, the ages of these cities were preliminarily estimated through the characteristics of the structures and archaeological remains (such as ceramic chips, bricks, etc.), and the fragmentary historical documents relating to this area. Radiocarbon dating has been found to be a more reliable method for determining the absolute ages of ancient cities (Lu et al., 2010) than using characteristics of artifacts found in the Tibetan Plateau (Sun et al., 2010; Hudson et al., 2014). In this study, we investigate ancient cities in east Qinghai Province by collecting reliable dating materials, using the accelerator mass spectrometry (AMS) radiocarbon dating method to determine the ages of these cities, and thus providing a valuable dataset for the reconstruction of human settlement history during the historical period. We also compare the radiocarbon dates with the historical documents and high resolution paleoclimate records to further explore the potential causes behind the emergence of these ancient cities.

2 Study area

The study area (35°20′–37°32′N, 96°23′–103°04′E) is located in the northeastern Tibetan Plateau, northwest China. The investigated ancient cities are distributed in the eastern Qaidam Basin, the Qinghai Lake Basin, the Huangshui River Valley, the upper Yellow River Valley, and the Datong River Valley (Fig. 1), stretching about 500 km from Dulan County in the west to Minhe County in the east. The mean annual temperature ranges from –0.6°C – 8.1°C, and the mean annual precipitation ranges from 37.9 – 400 mm. The altitude gradually declines from west to east: the highest elevation is 5,536 m a.s.l. in Dulan County and the lowest is 1,650 m a.s.l. in Minhe County.

3 Materials and methods

We identified 47 ancient cities by remotely sensed imagery (Fig. 2), conducting an archaeological survey in east Qinghai Province (Fig. 1), and collecting 54 radiocarbon dating samples from these ancient cities, including two samples from 7 cities and one sample from the remaining 40. The dated samples included charred charcoal, grass, and sheep droppings from the cultural layers within the cities (Fig. 3(a), 3(b)), and dead wood or tree bark found in the walls around the cities, also used for their construction (Fig. 3(c)–3(f)). In order to minimize the "old wood effect" of radiocarbon dating of charcoal (McFadgen, 1982; Schiffer, 1986; Gavin, 2001; Dong et al., 2014), we selected the outermost parts of the wood for dating.

All 54 samples were dated using AMS at Peking University, China. Ages were calibrated using Calib (v.7.0.2) (Stuiver and Reimer, 1993) and the INTCAL13

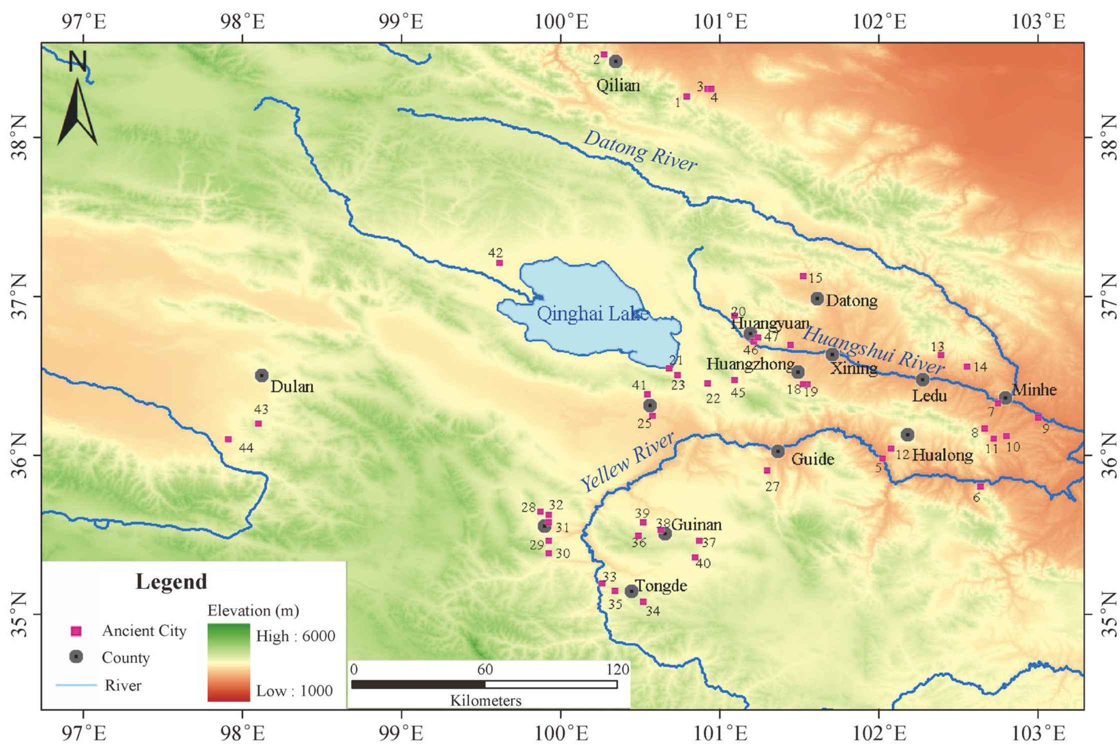

Fig. 1 Distribution of the dated ancient cities in east Qinghai Province. 1 Gufang; 2 Langshetou; 3 Biandugou; 4 Sanjiaocheng; 5 Niangmo; 6 Baojia; 7 Shancheng; 8 Guchengyuan; 9 Xiachuankou; 10 Heichengzi; 11 Beigu; 12 Qihouang; 13 Hei; 14 Heichengzi; 15 Yangjiacheng; 16 Xinchengbao; 17 Duobaxin; 18 Duobajiu; 19 Heichengbao; 20 Sanjiao; 21 Qunkejiala; 22 Nahailie; 23 Jiayi; 24 Huangkebao; 25 Shangtamai; 26 Xiazhatan; 27 Heigu; 28 Watan; 29 Xiatang; 30 Tadong; 31 Shanabao; 32 Longqu; 33 Shanggamaoqibao; 34 Douhouzong; 35 Longbatan; 36 Dongciduo; 37 Duojiangtang; 38 Duoguotan; 39 Tawa; 40 Hangnaishaga; 41 Jialabei; 42 Fuxi; 43 Kaoxiaotu; 44 Hongxin; 45 Hacheng; 46 Nangucheng; 47 Beigucheng.

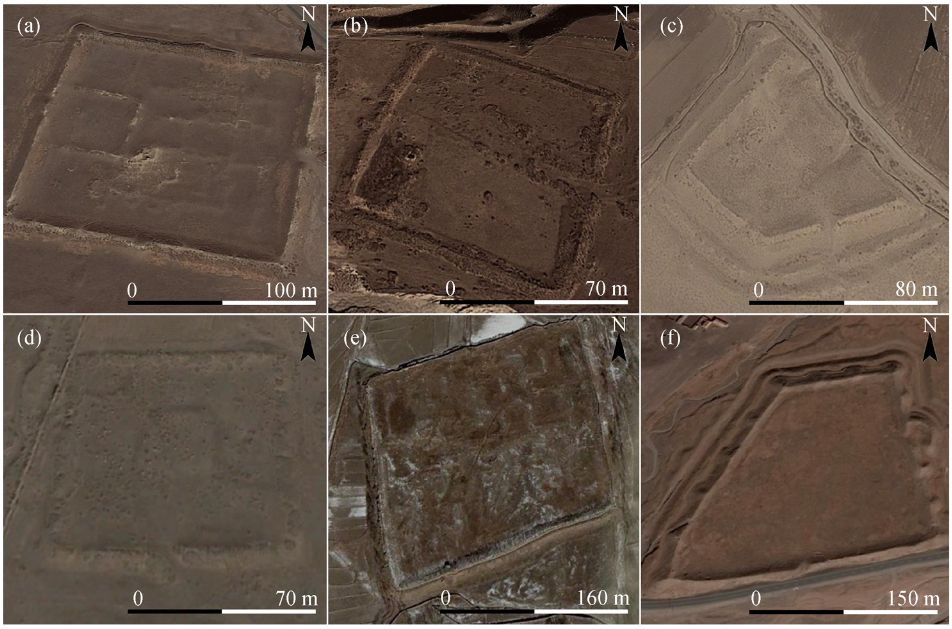

Fig. 2 Remote sensing images of six selected ancient cities in Qinghai Province. (a) Fuxi; (b) Xiatang; (c) Hongxing; (d) Huangkebao; (e) Jialabei; (f) Sanjiao.

Fig. 3 Sampling positions in ancient cities. (a) and (b): Cultural layers in the Langshetou and Sanjiaocheng ancient cities; (c) and (d): Dead wood and grass in the walls of the Niangmo and Hacheng ancient cities; (e) and (f): Sampling from the walls of the Ketu and Kaoxiaotu ancient cities.

Calibration curve (Reimer et al., 2013). All ages were reported as “Cal AD” (“Calendar years after AD 1”) or “Cal BC” (“Calendar years before AD 1”).

The probability distribution of the 54 radiocarbon dates was summed using Calib (v.7.0.2) (Stuiver and Reimer, 1993). The summed probability plots of radiocarbon data have been widely used in archaeological research to infer prehistoric population fluctuations (Gamble et al., 2005; Shennan and Edinborough, 2007; Bamforth and Grund, 2012) and occupational intensity (Barton et al., 2007); however, caution must be used by considering the distorting effects of site sampling, sample size, radiocarbon calibration, and taphonomic bias (Williams, 2012). In this paper, the summed probability plot of radiocarbon dates is used as an auxiliary proxy to deduce when those ancient cities were intensively built or repaired.

4 Results

The radiocarbon dating results are shown in (Table 1). The oldest calibrated date is from Tawa in Guinan County and ranges between 474 and 390 Cal BC, corresponding to the Spring and Autumn Period (770 BC−476 BC). Four

Table 1 Calibrated radiocarbon data from the investigated ancient cities in Qinghai Province

Lab number	Dating material	Ancient city	Location	Dating method	Sampling position	Radiocarbon age (BP)	Calibrated age	
							1σ (68.2%)	2σ (95.4%)
BA120344	Charcoal	Gufang	Qilian	AMS	Cultural layer inside the city	1085±40	898AD (23.3%) 925AD 944AD (44.9%) 995AD	880AD (95.4%) 1024AD
BA120345	Charcoal	Langshetou	Qilian	AMS	Cultural layer inside the city	1260±35	688AD (68.2%) 771AD	668AD (79.6%) 778AD 790AD (15.8%) 868AD
BA120346	Charcoal	Langshetou	Qilian	AMS	Cultural layer inside the city	1550±35	430AD (47.5%) 493AD 510AD (4.6%) 518AD 528AD (16.1%) 551AD	420AD (95.4%) 584AD
BA120347	Charcoal	Biandugou	Qilian	AMS	Inside rammed earth layer of city wall	1370±35	638AD (68.2%) 676AD	601AD (92.6%) 694AD 746AD (2.8%) 763AD
BA120348	Charcoal	Sanjiaocheng	Qilian	AMS	Cultural layer inside the city	1090±60	892AD (68.2%) 1014AD	774AD (95.4%) 1030AD
BA120349	Grass	Niangmo	Jianzha	AMS	Inside rammed earth layer of city wall	990±35	997AD (5.1%) 1006AD 1011AD (38.0%) 1046AD 1092AD (20.7%) 1120AD 1140AD (4.5%) 1147AD	986AD (53.0%) 1059AD 1065AD (42.4%) 1154AD
BA120350	Charcoal	Baojia	Minhe	AMS	Inside rammed earth layer of city wall	1120±30	893AD (68.2%) 970AD	778AD (1.7%) 790AD 809AD (0.5%) 815AD 826AD (1.4%) 841AD 862AD (91.8%) 994AD
BA120351	Charcoal	Baojia	Minhe	AMS	Inside rammed earth layer of city wall	955±35	1026AD (20.0%) 1050AD 1082AD(36.0%) 1127AD 1135AD (12.3%) 1151AD	1020AD (95.4%) 1159AD
BA120352	Charcoal	Shancheng	Minhe	AMS	Inside rammed earth layer of city wall	415±45	1434AD (57.2%) 1497AD 1507AD (2.0%) 1511AD 1601AD (9.1%) 1616AD	1420AD(71.0%) 1525AD 1556AD(24.4%) 1632AD

(*Continued*)

Lab number	Dating material	Ancient city	Location	Dating method	Sampling position	Radiocarbon age (BP)	Calibrated age	
							1σ (68.2%)	2σ (95.4%)
BA120354	Charcoal	Guchengyuan	Minhe	AMS	Inside rammed earth layer of city wall	1235±30	694AD (34.7%) 746AD 763AD (10.4%) 778AD 791AD (7.6%) 805AD 814AD (5.0%) 825AD 841AD (10.5%) 862AD	686AD (95.4%) 880AD
BA120355	Twig	Xiachuankou	Minhe	AMS	Inside rammed earth layer of city wall	1075±25	904AD (12.1%) 916AD 9665AD (50.6%) 998AD 1006AD (5.4%) 1012AD	898AD (19.4%) 924AD 946AD (76.0%) 1018AD
BA120358	Charcoal	Heichengzi	Minhe	AMS	Inside rammed earth layer of city wall	960±35	1024AD (22.4%) 1050AD 1084AD (34.5%) 1125AD 1136AD (11.3%) 1150AD	1018AD (95.4%) 1158AD
BA120359	Charcoal	Beigu	Minhe	AMS	Inside rammed earth layer of city wall	1290±25	676AD (42.2%) 713AD 744AD (26.0%) 765AD	665AD (95.4%) 770AD
BA120360	Charcoal	Qihouang	Hualong	AMS	Inside rammed earth layer of city wall	1255±20	722AD (14.7%) 740AD 766AD (10.7%) 778AD 790AD (25.0%) 829AD 838AD (17.9%) 865AD	695AD (0.9%) 700AD 710AD (21.4%) 745AD 764AD (73.1%) 882AD
BA120361	Charcoal	Hei	Ledu	AMS	Inside rammed earth layer of city wall	1145±25	780AD (3.4%) 787AD 876AD (23.5%) 906AD 915AD (41.3%) 968AD	776AD (6.1%) 792AD 802AD (11.8%) 848AD 854AD (77.5%) 974AD
BA120362	Charcoal	Hei	Ledu	AMS	Inside rammed earth layer of city wall	1385±20	644AD (68.2%) 660AD	618AD (95.4%) 668AD
BA120363	Charcoal	Heichengzi	Ledu	AMS	Cultural layer inside the city	970±20	1022AD (35.7%) 1045AD 1095AD (27.9%) 1120AD 1142AD (4.6%) 1146AD	1018AD (41.9%) 1052AD 1081AD (53.5%) 1152AD
BA120364	Charcoal	Heichengzi	Ledu	AMS	Cultural layer inside the city	1010±20	996AD (68.2%) 1029AD	986AD (95.4%) 1040AD
BA120365	Charcoal	Yangjiacheng	Datong	AMS	Inside rammed earth layer of city wall	1220±25	728AD (6.7%) 737AD 768AD (8.6%) 778AD 790AD (52.9%) 867AD	696AD (0.8%) 700AD 710AD (16.1%) 745AD 764AD (78.5%) 886AD
BA120366	Charcoal	Xinchengbao	Huangz-hong	AMS	Inside rammed earth layer of city wall	1245±20	694AD (56.5%) 746AD 763AD (11.7%) 774AD	682AD (81.9%) 779AD 790AD (7.8%) 830AD 836AD (5.7%) 865AD

(*Continued*)

Lab number	Dating material	Ancient city	Location	Dating method	Sampling position	Radiocarbon age (BP)	Calibrated age	
							1σ (68.2%)	2σ (95.4%)
BA120367	Grass	Duobaxin	Huangzhong	AMS	Inside rammed earth layer of city wall	95±20	1697AD (23.8%) 1725AD 1814AD (17.1%) 1835AD 1877AD (15.7%) 1896AD 1902AD (11.6%) 1916AD	1690AD (26.5%) 1729AD 1810AD (68.9%) 1922AD
BA120368	Charcoal	Duobajiu	Huangzhong	AMS	Inside rammed earth layer of city wall	1860±25	90AD (6.5%) 100AD 123AD (42.1%) 180AD 186AD (19.6%) 214AD	82AD (95.4%) 226AD
BA120369	Charcoal	Heichengbao	Huangzhong	AMS	Inside rammed earth layer of city wall	1035±20	993AD (68.2%) 1018AD	980AD (95.4%) 1025AD
BA120370	Charcoal	Heichengbao	Huangzhong	AMS	Inside rammed earth layer of city wall	895±30	1048AD (29.9%) 1086AD 1123AD (9.2%) 1138AD 1149AD (29.0%) 1189AD	1039AD (95.4%) 1215AD
BA120371	Charcoal	Sanjiao	Huangyuan	AMS	Inside rammed earth layer of city wall	1205±40	770AD (68.2%) 882AD	688AD (92.4%) 898AD 924AD (3.0%) 944AD
BA120372	Charcoal	Qunkejiala	Gonghe	AMS	Inside rammed earth layer of city wall	880±20	1154AD (68.2%) 1210AD	1048AD (18.5%) 1084AD 1124AD (3.3%) 1136AD 1150AD (73.6%) 1218AD
BA120373	Charcoal	Nahailie	Gonghe	AMS	Cultural layer inside the city	890±30	1050AD (23.7%) 1083AD 1126AD (5.3%) 1136AD 1150AD (39.2%) 1206AD	1040AD (92.4%) 1108AD 1116AD (3.0%) 1218AD
BA120374	Charcoal	Jiayi	Gonghe	AMS	Cultural layer inside the city	1035±25	990AD (68.2%) 1020AD	970AD (95.4%) 1030AD
BA120375	Charcoal	Huangkebao	Gonghe	AMS	Cultural layer inside the city	1080±20	901AD (20.0%) 920AD 960AD (48.2%) 994AD	897AD (24.5%) 925AD 943AD (70.9%) 1016AD
BA120376	Charcoal	Shangtamai	Gonghe	AMS	Inside rammed earth layer of city wall	305±20	1522AD (48.9%) 1575AD 1585AD (3.1%) 1590AD 1625AD (16.2%) 1644AD	1492AD (72.0%) 1602AD 1615AD (23.4%) 1649AD
BA120377	Charcoal	Xiazhatan	Gonghe	AMS	Cultural layer inside the city	275±25	1526AD (29.5%) 1554AD 1632AD (38.7%) 1658AD	1520AD (46.0%) 1592AD 1619AD (47.5%) 1665AD 1784AD (1.9%) 1794AD

(*Continued*)

Lab number	Dating material	Ancient city	Location	Dating method	Sampling position	Radiocarbon age (BP)	Calibrated age	
							1σ (68.2%)	2σ (95.4%)
BA120378	Charcoal	Heigu	Guide	AMS	Inside rammed earth layer of city wall	295±25	1522AD (49.0%) 1572AD 1630AD (19.2%) 1648AD	1496AD (1.9%) 1506AD 1512AD (65.3%) 1601AD 1616AD (28.2%) 1654AD
BA120379	Charcoal	Watan	Xinghai	AMS	Inside rammed earth layer of city wall	1140±25	882AD (21.2%) 906AD 915AD (47.0%) 968AD	777AD (4.4%) 791AD 804AD (7.6%) 843AD 859AD (83.5%) 979AD
BA120380	Charcoal	Xiatang	Xinghai	AMS	Inside rammed earth layer of city wall	1915±20	66AD (36.3%) 90AD 99AD (31.9%) 124AD	30AD (1.5%) 37AD 51AD (93.9%) 130AD
BA120381	Charcoal	Tadong	Xinghai	AMS	Cultural layer inside the city	595±25	1312AD (54.2%) 1358AD 1388AD (14.0%) 1400AD	1298AD (70.8%) 1370AD 1380AD (24.6%) 1410AD
BA120382	Charcoal	Shanabao	Xinghai	AMS	Cultural layer inside the city	1055±20	986AD(68.2%) 1016AD	904AD(3.3%)916AD 967AD (92.1%) 1023AD
BA120383	Charcoal	Longqu	Xinghai	AMS	Cultural layer inside the city	670±25	1282AD (40.3%) 1302AD 1366AD (27.9%) 1382AD	1276AD (54.3%) 1316AD 1355AD (41.1%) 1390AD
BA120384	Charcoal	Longqu	Xinghai	AMS	Cultural layer inside the city	415±20	1443AD (68.2%) 1467AD	1436AD (93.4%) 1490AD 1602AD (2.0%) 1609AD
BA120385	Charcoal	Shanggamao-qibao	Tongde	AMS	Cultural layer inside the city	1035±25	990AD (68.2%) 1020AD	970AD (95.4%) 1030AD
BA120386	Charcoal	Douhouzong	Tongde	AMS	Inside rammed earth layer of city wall	2030±25	54BC (66.4%) 6AD 12AD (1.8%) 16AD	110BC (93.1%) 30AD 36AD (2.3%) 50AD
BA120387	Charcoal	Douhouzong	Tongde	AMS	Inside rammed earth layer of city wall	1055±20	986AD (68.2%) 1016AD	904AD (3.3%) 916AD 967AD (92.1%) 1023AD
BA120388	Charcoal	Longbatan	Tongde	AMS	Cultural layer inside the city	1055±20	986AD (68.2%) 1016AD	904AD (3.3%) 916AD 967AD (92.1%) 1023AD
BA120389	Charcoal	Dongciduo	Guinan	AMS	Cultural layer inside the city	1000±20	998AD (5.4%) 1004AD 1012AD (62.8%) 1035AD	988AD (87.8%) 1045AD 1096AD (6.8%) 1120AD 1142AD (0.7%) 1146AD
BA120390	Charcoal	Duojiangtang	Guinan	AMS	Cultural layer inside the city	1030±25	994AD (68.2%) 1020AD	972AD (95.4%) 1032AD
BA120391	Charcoal	Duoguotan	Guinan	AMS	Cultural layer inside the city	985±25	1016AD (44.3%) 1045AD 1095AD (20.6%) 1120AD 1142AD (3.3%) 1146AD	994AD (56.3%) 1051AD 1082AD (39.1%) 1152AD
BA120392	Charcoal	Tawa	Guinan	AMS	Inside rammed earth layer of city wall	2365±25	474BC (17.6%) 444BC 431BC (50.6%) 394BC	512BC (95.4%) 390BC

(*Continued*)

Lab number	Dating material	Ancient city	Location	Dating method	Sampling position	Radiocarbon age (BP)	Calibrated age	
							1σ (68.2%)	2σ (95.4%)
BA120394	Charcoal	Hangnaishaga	Guinan	AMS	Cultural layer inside the city	1095±25	900AD (25.6%) 921AD 950AD (42.6%) 986AD	890AD (94.2%) 997AD 1006AD (1.2%) 1012AD
BA120206	Charcoal	Jialabei	Gonghe	AMS	Cultural layer inside the city	1140±25	882AD (21.2%) 906AD 915AD (47.0%) 968AD	777AD (4.4%) 791AD 804AD (7.6%) 843AD 859AD (83.5%) 979AD
BA120207	Charred sheep dropping	Fuxi	Gonghe	AMS	Cultural layer inside the city	370±25	1458AD (49.6%) 1516AD 1596AD (18.6%) 1618AD	1450AD (49.6%) 1524AD 1558AD (18.6%) 1632AD
BA120208	Tree bark	Kaoxiaotu	Dulan	AMS	Inside rammed earth layer of city wall	1285±25	680AD (40.5) 715AD 744AD (27.7%) 766AD	668AD (95.4%) 770AD
BA120209	Charcoal	Hongxin	Dulan	AMS	Cultural layer inside the city	1885±25	74AD (68.2%) 134AD	65AD (95.4%) 214AD
BA120210	Grass	Hacheng	Huan-gyuan	AMS	Inside rammed earth layer of city wall	355±35	1470AD (33.4%) 1522AD 1572AD (34.8%) 1630AD	1453AD (44.0%) 1530AD 1538AD (51.4%) 1635AD
BA120211	Charcoal	Nangucheng	Huan-gyuan	AMS	Inside rammed earth layer of city wall	1115±35	893AD (68.2%) 975AD	778AD (2.0%) 790AD 826AD (1.6%) 840AD 863AD (91.8%) 1015AD
BA120212	Charcoal	Beigucheng	Huan-gyuan	AMS	Inside rammed earth layer of city wall	1040±40	970AD (68.2%) 1028AD	892AD (93.5%) 1044AD 1102AD (1.9%) 1118AD

calibrated dates from Hongxin in Dulan County, Douhouzong in Tongde County, Xiatan in Xinghai County, and Duobajiu in Huangzhong County, range between 54 Cal BC and 214 Cal AD, correspond to the Han Dynasty (202 BC–AD 220). One calibrated date from Langshetou in Qilian County ranges between 430 and 584 Cal AD, corresponding to the Wei Jin Southern and Northern Dynasties (AD 220–AD 581).

Ten calibrated dates range between 618 and 886 Cal AD, corresponding to the Tang Dynasty (AD 618–AD 907). Eighteen calibrated dates range between 960 and 1218 Cal AD, corresponding to the Song Dynasty (AD 960–AD 1279). Ten calibrated dates range between 882 and 1158 Cal AD, corresponding to the transitional period that partly overlaps the late Tang Dynasty, the Five Dynasties and Ten Kingdoms period (AD 907–AD 960), and the Song Dynasty.

Two calibrated dates from Tadong and Longqu in Xinghai County range between 1298 and 1410 Cal AD, corresponding to the transitional period between the Yuan Dynasty (AD 1271–AD 1368) and Ming Dynasty (AD 1368–AD 1644). Four calibrated dates, from Shancheng in Minhe County, Fuxi in Gonghe County, Longqu in Xinghai County, and Hacheng in Huangyuan County, range between 1436 and 1635 Cal AD, corresponding to the Ming Dynasty. Three calibrated dates, from Heigu in Guide County and Shangtamai and Xiazhatan in Gonghe County range between 1522 and 1654 Cal AD, corresponding to the transitional period between the Ming Dynasty and Qing Dynasty (AD 1644–AD 1911). One calibrated date from Duobaxin in Huangzhong County ranges between 1697 and 1922 Cal AD, which basically belongs to the Qing Dynasty.

5 Discussion

5.1 When human built or repaired ancient cities in northeastern Tibetan Plateau?

Radiocarbon dates from ancient cities can be used to determine when they were built, repaired, or occupied. Wood charcoals sampled from the rammed earth layer inside walls of ancient cities were the standard dating materials used in this study (Fig. 3, Table 1). The dating results may represent initial construction or maintenance of these cities.

The ancient city of Tawa in Guinan County dates back to the Spring and Autumn Period, a turbulent period in Chinese history. However, that date may be problematic because at that time, east Qinghai Province was occupied by aboriginal nomadic tribes, collectively called "*Qiang*" (Cui et al., 1999), and no ancient city built by these tribes has ever been reported or recorded. Furthermore, the date of Tawa is much older than the dates of the other four ancient cities in Guinan County, all of which date to the Song Dynasty (Table 1). In addition, a tile decorated with a lotus flower, prevalent during the Tang dynasty, was found in one of the eaves of a structure in Tawa and sampled (Supplementary file). This evidence suggests that the radiocarbon date may be older than the period of occupation of Tawa. This could possibly be due to: 1) the "old wood" effect of radiocarbon dating of charcoal, which can range from decades to centuries in northwest China (Dong et al., 2014), or 2) the reuse of old materials (such as charcoal) from early human occupation for the purpose of building a wall. Artifacts from the Kayue culture (1600 BC–600 BC) were also found in the Tawa site during an archaeological survey (Bureau of National Cultural Relics, 1996).

Four ancient cities were dated to the Han Dynasty (Table 1), when the Chinese central government firstly affected and controlled east Qinghai Province. According to historic documents (*Hou Hanshu, Xiqiang Zhuan* and *Hanshu, Zhaodi Ji*), Emperor *Hanwu* (156 BC–87 BC), detached general *Li Xi,* and a 100,000-strong army suppressed the *Qiang* in the Huangshui River Valley and recaptured the area west to Qinghai Lake and Chaka Salt Lake in 111 BC. Subsequently, the government of the western Han Dynasty (202 BC–AD 9) began to establish prefectures and counties to control the area. According to historic texts (*Hanshu, Wangmang Zhuan*), Wangmang, who controlled Han Dynasty during AD 8–AD 23, built the ancient cities of Xihaijun in the Qinghai Lake Basin and Zhidonglajia in Xinghai County. The Eastern Han Dynasty government (AD 9–AD 220) set up Xiping *Jun* (*Jun* is an administrative district in Chinese history), the predecessor of modern Xining. Since Douhouzong, Xiatan and Duobajiu are located in the areas (Xinghai, Huangzhong and Tongde counties) controlled by the Han Dynasty, their radiocarbon dates fit well with this historical evidence. The date of Hongxin in Dulan County is more open to debate, as this area was controlled by the *Tuyuhun* kingdom that was established in the area around AD 330, and collapsed during the Tang Dynasty. We were unable to find any records for the existence of ancient cities in Dulan County during the Han Dynasty in historic documents.

Only Langshetou in Qilian County was dated to the "Wei Jin Southern and Northern Dynasties" period, another turbulent phase of Chinese history. According to the "*Jin Shu*" text, this period covered the years between AD 397 and AD 414. East Qinghai Province was essentially controlled by both the *Nan Liang* kingdom, located in the Huangshui River Valley, and the *Tuyuhun* kingdom, located in the Qaidam Basin. Qilian County is located in the Datong River Valley, an important channel connecting the Huangshui River Valley and the Hexi Corridor. This area was controlled by the *Hou Liang* kingdom between AD 386 and AD 403. Frequent wars occurred between the *Nan Liang* and *Hou Liang* kingdoms. Two dates were obtained from Langshetou, one of which dated to AD 430–AD 560 (BA120346) and the other at AD 685–AD 780 (BA120345). These dates suggest that Langshetou may have been built during the Wei Jin Southern and Northern Dynasties and repaired during Tang Dynasty.

The number of ancient cities in east Qinghai Province noticeably increased during the Tang Dynasty when compared to earlier periods. The summed probability distribution of radiocarbon dates is much higher during this period than during former periods (Fig. 4). This suggests that in this area, ancient cities might have been built or repaired in large numbers during the Tang Dynasty. According to the dating results (Table 1), the ten ancient cities of Tang Dynasty are primarily located in the Huangshui and Datong River Valleys, and constructed between 600 Cal AD and 800 Cal AD (Table 1). These results are in agreement with the records found in historical documents. The *Tubo* kingdom prospered during the middle of the sixth century, and unified the entire Tibetan area by AD 644, before expanding toward east Qinghai Province. The *Tubo* kingdom defeated the *Tuyuhun* kingdom in AD 663, which seriously threatened the border of the Tang Dynasty lands. To defend against the expansion of the *Tubo* kingdom in east Qinghai Province, the Tang central government established a military defense system in the Huangshui River Valley, and set up the *Dudufu* (a high-class military command authority) in *Shan Zhou* (Xining area). In AD 677, the number of garrison troops in the area reached 14,000 (Cui et al., 1999). In addition, the population in Qinghai Province increased rapidly from 219,000 in AD 609 to 421,000 in AD 752 (Zhao and Xie, 1998) (Fig. 4), according to an analysis of historical records. The military confrontation between the Tang and *Tubo* governments might have prompted the construction of cities in east Qinghai Province, with Kaoxiaotu in Dulan County likely controlled by the *Tubo* government, while the other nine ancient cities east to the Qaidam Basin were likely governed by the Tang government.

According to the dating results, the number of ancient cities reached a maximum during the transitional period between the late Tang Dynasty, the Five Dynasties and Ten Kingdoms period, and the early Song Dynasty, especially

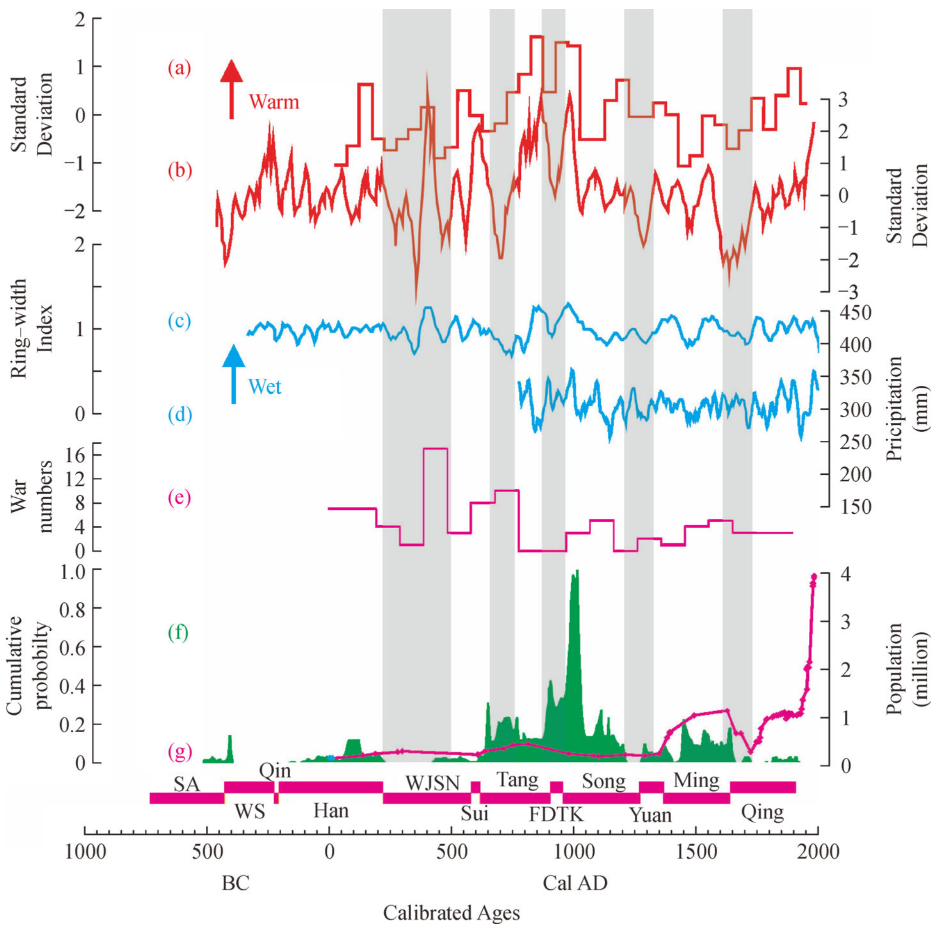

Fig. 4 Comparison between paleoclimate records, population fluctuation, and dates of ancient cities in northeast Tibetan Plateau: (a) 50-year mean temperature in Northeast Tibetan plateau (Yang et al., 2003); (b) Temperatures during the last 2485 years in the mid-eastern Tibetan Plateau inferred from tree rings (Zhang et al., 2003); (c) The 2326- year ring-width chronology of Sabina przewalskii Kom (Liu et al., 2009); (d) Precipitation reconstruction since AD 775 based on tree rings from the Qilian Mountains (Zhang et al., 2011); (e) War numbers during historic periods in east Qinghai Province (Compilation of Chinese Military History, 2002; Gu, 2005); (f) Historical population in Qinghai Province (Zhao and Xie, 1998); g. Summed probability distributions of 54 radiocarbon dates from 47 ancient cities in east Qinghai Province. SA–Spring and Autumn Period; WS–War States Period; WJNS–Wei Jin Southern and Northern Dynasties period; FDTK–Five Dynasties and Ten Kingdoms period. Black shadows show relatively cold and dry periods during historical times.

between 1000–1100 Cal AD, the period with the highest summed probability distributions of radiocarbon dates (Fig. 4(g)). According to historical records, east Qinghai Province was controlled by the *Qingtang* kingdom during that period, which allied with the Song government to fight the *Xixia* kingdom (AD 1038–AD 1227), a strong regime built by *Li Yuanhao* in AD 1038. Many major battles were fought between the troops of the *Xixia* and *Qingtang* kingdoms in the eleventh century in east Qinghai Province. For example, *Su Nuer*, a *Xixia* general, led 25,000 troops against the *Qingtang* kingdom in AD 1035, ending in defeat in the ancient city of Maoniu in Datong County, according to *Songshi, Xiaguo Zhuan*. The *Xixia* kingdom continually sent troops to the Huangshui and Upper Yellow River Valleys between AD 1035–AD 1062, but failed to take the area due to the strong resistance of the *Qingtang* kingdom. Radiocarbon dates are highly concentrated during that period, suggesting that the strong need for military defense contributed to the building and/or repair of ancient cities in the area. The results of radiocarbon dating may accurately reflect the true ages of the cities of that period. The population in Qinghai Province declined between the late Tang Dynasty and early Song Dynasty (Zhao and Xie, 1998) (Fig. 4), likely induced by frequent wars during the early Song Dynasty in the area. The climate was warm and humid during that time (Fig. 4), but was not likely the cause for the decrease in population.

The summed probability distribution of radiocarbon dates declined post Song Dynasty period. Only ten ancient cities were dated to that period, most of which fell into the Ming Dynasty period (Fig. 4, Table 1). Two dates from Longqu and Tadong in Xinghai County correspond well with the Yuan Dynasty. According to the records in *Yuan Shi*, the primary administrative center of the Yuan government on the south bank of the Yellow River was located in Guide Prefecture, adjacent to Xinghai County. Seven ancient cities are dated to the Ming Dynasty period. The Northern *Yuan* (AD 1368–AD 1402) was the primary threat to the central government of early Ming Dynasty. Abundant remains of the Great Wall dated to the Ming Dynasty date were found by the archaeological survey (Bureau of National Cultural Relics, 1996), probably due to the defense against the invasion by Mongolian tribes, such as the Northern *Yuan* and the later *Datan*. The Ming government also set up many military districts in east Qinghai Province, covering the areas of the Qinghai Lake Basin, the Gonghe Basin, and the Huangshui River Valley. All six cities that were dated to the Ming Dynasty are located in these regions. The population in Qinghai Province was relatively high during the Ming Dynasty (Zhao and Xie, 1998) (Fig. 4), which may suggest that these ancient cities might also have promoted human settlement during that period.

Only the Duobaxin ancient city in Huangzhong county was dated to the Qing Dynasty. However, according to the results of the second national archaeological survey (Bureau of National Cultural Relics, 1996), the number of sites dating to the Qing Dynasty is higher than for any other dynasty, and the population of Qinghai Province was also high during this period (Zhao and Xie, 1998). This suggests that the rarity of ancient cities dated to the Qing period, may not indicate that there were only a small number of ancient cities in this period. Rather, the absence of radiocarbon dates from this period may relate to the destruction of these ancient cities during recent decades, as modern cities very likely developed in the places that the Qing ancient cities are located.

Comparing results from those 7 ancient cities from which two dates were obtained, the difference between the two dates at most of these sites is less than two hundred years (Table 1), while the difference between the two radiocarbon dates from Douhouzong in Tongde county is around one thousand years. Although this site is probably influenced by the "old wood" effect of radiocarbon dating, multiple or sustained occupation of the same ancient cities could also affect the dating results. For example, the Fuxi ancient city had once been used as the capital of the *Tuyuhun* kingdom during the "Wei Jin Southern and Northern Dynasties" period, but was dated to Ming Dynasty in this work. This indicates that the ancient city had been occupied during different historical periods.

5.2 The influencing factors behind the construction of ancient cities in northeastern Tibetan Plateau.

Construction of ancient cities in northeastern Tibetan Plateau is probably strongly linked to the geopolitical situations, for the area is an important boundary area between nomadic tribes and agricultural Han people during historical periods. While aggression wars between agriculturalist and pastoralist empires are closely related to climate change, especially the evident decline of temperature and precipitation, which resulted in the ecological deterioration and social instability (Zhang et al., 2010; Zhang et al., 2015). Based on this premise, the dating results of ancient cities in this study is compared with historical documentary records and high-resolution paleoclimate reconstructions, to examine how geopolitical variables and climate change affected the construction of ancient cities in northeastern Tibetan Plateau.

The comparison between proxies from tree rings and ice core paleoclimate records in northeastern Tibetan Plateau (Yang et al., 2003; Zhang et al., 2003; Liu et al., 2009; Zhang et al., 2011), war number in the area and the summed probability plot of 54 radiocarbon dates in this text is shown in Fig. 4. Most ancient cites in the area were built during Tang, early Song and Ming Dyansties according to the dating results, when war frequency was relatively high due to the conflicts and confrontations of different powerful politics, including Tang and *Tubo* empires, Northern Song, *Xixia* and *Qingtang* regimes, Ming and Northern Yuan regimes. War frequency was the highest in northeastern Tibetan Plateau during late Wei Jin Southern and Northern Dynasties (Fig. 4(e)), however, only one ancient city is dated to that period. According to the records of historical documents, more than 16 ancient cities in northeastern Tibetan Plateau were firstly built in Wei Jin Southern and Northern Dynasties (such as Shenna, Qunke, Shangtamai, Beigu), while well-preserved ancient cities were concentratedly dated between Tang and Song Dynasties, due to the repair and reinforcement of old cities during late periods (Zhao, 1986; Li, 1995). The control power of east Qinghai Province was struggled by different local regimes in Wei Jin Southern and Northern Dynasties, resulting in the frequent wars during the period. The positive correlation between the ages of ancient cities and the frequency of wars (Fig. 4(e) and 4(g)) suggests military confrontation of different geopolitics possibly led to the active demand of defense, and the construction and repair of ancient cities in northeastern Tibetan Plateau during historic times.

The multi-decadal severe decrease in temperature and precipitation could be the cause for the breakdown of food production, locust plagues, and uncontrollable crop prices, followed by social conflicts and frequent wars during the last two millennia (Zhang et al., 2010; Kennett et al., 2012; Zhang et al., 2015). Conversely, the multi-centennial warm and humid climate potentially promoted the thriving of powerful dynasties (such as Han, Tang, and Ming) in Chinese history (Yancheva et al., 2007; Zhang et al., 2008). The periods of temperature decline in northeastern Tibetan Plateau correspond well with the collapse of the Han, Tang, Song, and Ming dynasties, further suggesting that climate change was an influencing factor for alternation of Chinese dynasties. However, neither the variabilities of temperature nor precipitation were related to the summed probability of radiocarbon dates from the 47 ancient cities in northeastern Tibetan Plateau, indicating that the potential impact of climate change on the building of those cities is complex.

The probability distribution of the 54 radiocarbon dates is relatively low before the Tang Dynasty and evidently increased during the early Tang Dynasty when temperature and precipitation decreased and war frequency was high. These data suggest that climate deterioration may have led to an increase in military struggle for resources between the Tang and *Tubo* empires, and promoted the construction or repair of ancient cites. The probability increases again during the Five Dynasties and Ten Kingdoms period, a splitting and unrest period in central China that possibly related to climate deterioration (Zhang et al., 2008). War frequency was low during that period in northeastern Tibetan Plateau (Fig. 4(e)), likely due to the collapse of both Tang and *Tubo* empires, while frequent wars in nearby agriculturalist regimes may have promoted the reinforcement of cities in the area.

The summed probability of radiocarbon dates reached the maximum, while population declined, during early Song Dynasty when climate was warm and wet (Fig. 4). Favorable climate during the period likely promoted the rise of the *Qingtang* regime in the northeastern Tibetan Plateau and the *Xixia* and Northern Song empires in neighboring areas. These conditions resulted in the complex geopolitical structures and military confrontations in the area, followed by city construction and repair. The summed probability of radiocarbon dates was relatively low, and an increase in population was observed during the Ming and Qing Dynasties when the climate was typically warm and wet (Fig. 4) suggesting that the diminished occurrence of wars reduced the construction of ancient cities. Alternatively, favorable climate promoted human settlements in the northeastern Tibetan Plateau during these periods.

Our work suggests that the construction and repair of ancient cities in northeastern Tibetan Plateau are closely related to military conflict and confrontation, which were primarily affected by the emergence of different regimes in and around the area. Climate change may affect city construction and human settlements through its impact on the geopolitical situation. Climate change and geopolitical variables also influenced human settlement intensity in other areas of northwest China during historical periods, such as ancient Juyan Oasis (Hu and Li, 2014), ancient Minqin oasis (Xie et al., 2009) and Zhuanglang County (Dong et al., 2012).

6 Conclusions

Radiocarbon dates from ancient cities in the northeastern Tibetan Plateau suggest that most ancient cities were built or repaired during the Han Dynasty (202 BC−AD 220), the Tang Dynasty (AD 618−AD 907), the Five Dynasties and Ten Kingdoms period (AD 907−AD 960), the Song dynasty (AD 960−AD 1279), and the Ming Dynasty (AD 1368−AD 1644). This study contributed to our understanding of human settlement history in the Tibetan Plateau, given historical documentary records are deficient. Our work suggests that the number of ancient cities in east Qinghai Province during different historical periods relates closely to the military confrontations between strong regimes in the area, especially between Tang Dynasty and early Song Dynasty. The primary factor behind the building of these ancient cities is based on the geopolitical circumstances of east Qinghai Province and its surrounding areas, even though climate change may have also have been a contributing factor.

Acknowledgements This research was funded by the National Social Science Foundation of China (Grant Nos. 12&ZD151 and 12XKG006), the National Natural Science Foundation of China (Grant Nos. 41271218), Fundamental Research Funds for the Central Universities (lzujbky-2015-k09, lzujbky-2014-116), as well as the 111 Program (#B06026) of Chinese State Administration of Foreign Experts Affairs. We would like to thank Dr. Emma LIGHFOOT for improving the English, and Mr. Zhilin Shi for providing historical documents.

References

Aldenderfer M (2011). Peopling the Tibetan plateau: insights from archaeology. High Alt Med Biol, 12(2): 141–147

Bamforth D B, Grund B (2012). Radiocarbon Calibration curves, summed probability distributions, and early paleoindian population trends in North America. J Archaeol Sci, 39(6): 1768–1774

Barton L, Brantingham P J, Ji D (2007). Late Pleistocene climate change and Paleolithic cultural evolution in northern China: Implications from the Last Glacial Maximum. Late Quaternary Climate Change and Human Adaptation in Arid China, 9: 105–128 (in Chinese)

Brantingham P J, Gao X (2006). Peopling of the northern Tibetan Plateau. World Archaeol, 38(3): 387–414

Brantingham P J, Gao X, Madsen D B, Rhode D, Perreault C, Woerd J V D, Olsen J W (2013). Late Occupation of the High-Elevation Northern Tibetan Plateau Based on Cosmogenic, Luminescence, and Radiocarbon Ages. Geoarchaeology-an International Journal, 28(5): 413–431

Bureau of National Cultural Relics (1996). Atlas of Chinese Cultural Relics-Fascicule of Qinghai Province.Beijing: China Cartograghic Publishing House Press (in Chinese)

Chen F H, Dong G H, Zhang D J, Liu X Y, Jia X, An C B, Ma M M, Xie Y W, Barton L, Ren X Y, Zhao Z J, Wu X H, Jones M K (2015). Agriculture facilitated permanent human occupation of the Tibetan Plateau after 3600 BP. Science, 347(6219): 248–250

Compilation of Chinese Military History (2002). War Chronology of Chinese Imperial (part1, part2).Beijing: The people’s liberation army press (in Chinese)

Cui Y H, Zhang D Z, Du C S (1999). The History of Qinghai Province.

Xining: Qinghai People Press (in Chinese)
d'Alpoim Guedes J A, Lu H L, Hein A M, Schmidt A H (2015). Early evidence for the use of wheat and barley as staple crops on the margins of the Tibetan Plateau. Proc Natl Acad Sci USA, 112(18): 5625–5630
Dong G H, Jia X, Elston R, Chen F H, Li S C, Wang L, Cai L H, An C B (2013). Spatial and temporal variety of prehistoric human settlement and its influencing factors in the upper Yellow River valley, Qinghai Province, China. J Archaeol Sci, 40(5): 2538–2546
Dong G H, Wang Z L, Ren L L, Matuzeviciute G M, Wang H, Ren X Y, Chen F H (2014). A comparative study of 14C dating on charcoal and charred seeds from Late Neolithic and Bronze Age sites in Gansu and Qinghai Provinces, NW China. Radiocarbon, 56(1): 157–163
Dong G H, Yang Y, Zhao Y, Zhou A F, Zhang X J, Li X B, Chen F H (2012). Human settlement and human-environment interactions during the historical period in Zhuanglang County, western Loess Plateau, China. Quat Int, 281: 78–83
Gamble C, Davies W, Pettitt P, Hazelwood L, Richards M (2005). The archaeologiCal and genetic foundations of the European population during the Late Glacial: implications for 'Agricultural Thinking'. Camb Archaeol J, 15(2): 193–223
Gao C, Lei J, Jin F J (2013). The classification and assessment of vulnerability of man-land system of oasis city in arid area. Frontiers of Earth Science, 7(4): 406–416
Gavin D G (2001). Estimation of inbuilt age in radiocarbon ages of soil charcoal for firehistory studies. Radiocarbon, 43(1): 27–44
Gu Z Y (2005). *Dushi fangyu jiyao*. Beijing: Zhonghua Shuju Press (in Chinese)
Hu N K, Li X (2014). Spatial distribution of an ancient agricultural oasis in Juyan, northwestern China. Frontiers of Earth Science, 8(3): 338–350
Hudson A M, Olsen J W, Quade J (2014). Radiocarbon Dating of Interdune Paleo-Wetland Deposits to Constrain the Age of Mid-to-Late Holocene Microlithic Artifacts from the Zhongba site, South-western Qinghai-Tibet Plateau. Geoarchaeology-an International Journal, 29(1): 33–46
Kennett D J, Breitenbach S F, Aquino V V, Asmerom Y, Awe J, Baldini J U, Bartlein P, Culleton B J, Ebert C, Jazwa C, Macri M J, Marwan N, Polyak V, Prufer K M, Ridley H E, Sodemann H, Winterhalder B, Haug G H (2012). Development and disintegration of Maya political systems in response to climate change. Science, 338(6108): 788–791
Li Z X (1995). The examination of ancient cities in Qinghai Province, China. Xi'an: Northwestern University Press (in Chinese)
Liu Y, An Z S, Linderholm H W, Chen D L, Song H M, Cai Q F, Sun J Y, Tian H (2009). Annual temperatures during the last 2485 years in the mid-eastern Tibetan Plateau inferred from tree rings. Sci China Earth Sci, 52(3): 348–359
LuH Y, Xia X C, Liu J Q, Qin X G, Wang F B, Yidilisi A, Zhou L P, Mu G J, Jiao Y X, Li J Z (2010). A preliminary study of chronology for a newly discovered ancient city and five archaeological sites in Lop Nor, China. Chin Sci Bull, 55(1): 63–71
McFadgen B G (1982). Dating New Zealand archaeology by radio-carbon. N Z J Sci, 25: 379–392
Reimer P J, Bard E, Beck J W, Baillie M G L, Blackwell P G, Bronk Ramsey C, Buck C E, Cheng H, Edwards R L, Friedrich M, Grootes P M, Guilderson T P, Haflidason H, Hajdas I, Hatte C, Heaton T J, Hoffman D L, Hogg A G, Hughen K A, Kaiser K F, Kromer B, Manning S W, Niu M, Reimer R W, Richards D A, Scott E M, Southon J R, Staff R A, Turney C S M, van der Plicht J (2013). IntCal13 and Marine13 radiocarbon age calibration curves 0−50,000 years cal BP. Radiocarbon, 55(4): 1869–1887
Rhode D, Brantingham P J, Perreault C, Madsen D B (2014). Mind the gaps: testing for hiatuses in regional radiocarbon date sequences. J Archaeol Sci, 52: 567–577
Schiffer M B (1986). Radiocarbon dating and the "Old Wood" problem: the case of the Hohokam chronology. J Archaeol Sci, 13(1): 13–30
Shennan S, Edinborough K (2007). Prehistoric population history: from the Late Glacial to the Late Neolithic in central and northern Europe. J Archaeol Sci, 34(8): 1339–1345
Stuiver M, Reimer P J (1993). Extended 14C data base and revised CALIB 3.0 ^{14}C age Calibration program. Radiocarbon, 35(1): 215–230
Sun Y J, Lai Z P, Long H, Liu X J, Fan Q S (2010). Quartz OSL dating of archaeological sites in Xiao Qaidam Lake of the NE Qinghai-Tibetan Plateau and its implications for palaeoenvironmental changes. Quat Geochronol, 5(2-3): 360–364
Williams A N (2012). The use of summed radiocarbon probability distributions in archaeology: a review of methods. J Archaeol Sci, 39 (3): 578–589
Xie Y W, Chen F H, Qi J G (2009). Past desertification processes of Minqin Oasis in arid China. Int J Sustain Dev World Ecol, 16(6): 417–426
Yancheva G, Nowaczyk N R, Mingram J, Dulski P, Schettler G, Negendank J F W, Liu J Q, Sigman D M, Peterson L C, Haug G H (2007). Influence of the intertropical convergence zone on the East Asian monsoon. Nature, 445(74−77): 76–77
Yang B, Braeuning A, Shi Y F (2003). Late Holocene temperature fluctuations on the Tibetan Plateau. Quat Sci Rev, 22(21−22): 2335–2344
Zhang D D, Pei Q, Lee H F, Zhang J, Chang C Q, Li B S, Li J B, Zhang X Y (2015). The pulse of imperial China: a quantitative analysis of long-term geopolitical and climate cycles. Glob Ecol Biogeogr, 24 (1): 87–96
Zhang P Z, Cheng H, Edwards R L, Chen F H, Wang Y J, Yang X L, Liu J, Tan M, Wang X F, Liu J H, An C L, Dai Z B, Zhou J, Zhang D Z, Ji J H, Johnson K R (2008). A Test of climate, sun, and culture relationships from an 1810-year Chinese cave record. Science, 322 (5903): 940–942
Zhang Q B, Chen G D, Yao T D, Kang X C, Huang J G (2003). A 2326-year tree-ring record of climate variability on the northeastern Qinghai-Tibetan Plateau. Geophys Res Lett, 30(14): 1739–1742
Zhang Y, Tian Q H, Gou X H, Chen F H, Leavitt S W, Wang Y S (2011). Annual precipitation reconstruction since AD 775 based on tree rings from the Qilian Mountains, northwestern China. Int J Climatol, 31 (3): 371–381
Zhang Z B, Tian H D, Cazelles B, Kausrud K L, Brauning A, Guo F, Stenseth N C (2010). Periodic climate cooling enhanced natural disasters and wars in China during AD 10−1900. Proceedings of the Royal Society, 277(1701): 3745–3753
Zhao M, Kong Q P, Wang H W, Peng M S, Xie X D, Wang W Z, Jia Y, Duan J G, Cai M C, ZhaoS N, Cidanpingcuo , Tu Y Q, Wu S F, Yao YG, Bandelt H J, Zhang Y P (2009). Mitochondrial genome evidence

reveals successful Late Paleolithic settlement on the Tibetan Plateau. Proc Natl Acad Sci USA, 106(50): 21230–21235
Zhao S C (1986). Ancient cultures in Qinghai Province, China. Xining: Qinghai People’s Press (in Chinese)
Zhao W L, Xie S J (1998). The History of Human Population in China. Beijing: People’s Press (in Chinese)