Quaternary International 308-309 (2013) 36–41

Contents lists available at SciVerse ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

Redistribution of prehistoric Tarim people in response to climate change

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ARTICLE INFO

Article history:
Available online 29 January 2013

ABSTRACT

The role of climate change on civilization evolution, varying from a driving force, to a supporting role or just background noise, is an often-debated issue. This paper presents the occupation history of prehistoric civilization in the hyperarid Tarim Basin as a case study to evaluate the influences of environmental change. The prehistorical relics in the Tarim Basin are centered at two periods: prior to 3000 BP and after 2700 BP, showing an apparent centurial gap in occupation. The gap is bridged by the relics from the Kunlun highland, 3000–2600 BP. Previous palaeoclimatic reconstructions show an anti-phased moisture changes between the southern Tarim and the Kunlun highland during the past 5000 years. Placing the timing of relics in the climatic context, the prehistoric relics only occur during relatively wet periods, both on the Kunlun highlands and in the southern basin. The pattern indicates that moisture change is an important explanation for relic distributions in southern Tarim. During the succession of relics from both the basin and the highland, cultural complexities increased gradually from 3800 BP to the historical period, without any significant absences or collapses. This implies that ancient cultures can develop, although the people migrated between the highland and the basin. The results show that in this case environmental pressures have little influence on civilization evolution, even in such a fragile habitat and during prehistoric periods. Caution is required in assessing the influences of environmental change on civilizations.

1. Introduction

Profound impacts of climate and environmental changes on civilization around the world have been widely investigated by Quaternarists and archaeologists in past decades. However, to what extent the climate changes impact on the cultural evolution is a complex question. Attempts to link them have created controversial opinions that climate change can either play a key role that determines the civilization's development, be a supporting player that is significantly, but not solely, responsible for the civilization evolution, or be merely background noise whose influences are eclipsed by contemporaneous human activity (Catto and Catto, 2004).

The interactions between climate and culture are complex, requiring significant work. Efforts to understand the mode and strategy of past cultural response to climate change may prove instructive for estimating modern societal policy for an irreversible changing and uncertain future (Solomon et al., 2009). Studies on the relationship between culture and climate change include the classic works by Chang (1946) and Chu (1973), in which the possible impacts of climate on human society in China had been described. Hinsch (1988) presented a possible link to explain the Chinese dynastic cycles, with climate change influencing agriculture production by affecting temperature and rainfall, and resulting impacts on civilizations. Over the last few years, the climate–agriculture–war–population relationships in the preindustrial era reinforced Hinsch's hypothesis, and implied that long-term climate change has played an important role and imposed a wider ranging effect on human civilization than had previously been suggested (Zhang et al., 2005). With great care, these authors avoided commenting directly upon the causality between culture and climate in China.

However, the tacit reticence on China's climate–human relationships was challenged by new findings in recent years.

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http://dx.doi.org/10.1016/j.quaint.2013.01.021

Syntheses of palaeoclimatic data about the middle Holocene climatic transition points to the "Holocene Event 3" as the cause for the collapse of Neolithic cultures around Central China during the late third millennium BC (Wu and Liu, 2004). Furthermore, two recent palaeoclimatic records with time-resolution better than 5 years have shown that the decline of the East Asian summer monsoon, and thus reduced rainfall, was simply, but definitely, responsible for China's dynastic transition (Yancheva et al., 2007; Zhang et al., 2008). These authors appeared to be unfamiliar with the work of Chu (1973) and Hinsch (1988), and drew a plausible causality based on the faulty appreciation of history, as criticized by Fan (2010) and Zhang and Lu (2007). The linkage between climate change and China's ancient culture raise serious questions: to what extent does climate change impact on civilization? Moreover, how do the ancient people respond to the change?

A simple causality essentially simplified the question "how climate change caused culture evolution" to "climate change came first and culture evolution came later". Establishing a credible cause-effect relationship between climate and culture requires (1) ample archives to establish a cultural sequence, (2) reliable palaeoclimate indicators to reconstruct environment, and (3) explicit, provable causalities between them. The Tarim Basin, a hyperarid region in central Asia, is an ideal field lab to constrain this relationship, with relics spanning the late Neolithic to historical periods. As a case study, the ancient civilization of the Tarim Basin is placed in a climatic context to assess the influence of the climate change. To highlight the impacts of natural factors on humans, particular focus is on the prehistoric period in the Tarim Basin, spanning the known initial human settlement of the basin since ~3800 BP to the establishment of the Silk Road during the Han dynasty (206 BC–AD 220).

2. Archaeological archives from the southern Tarim

The Tarim Basin is bounded by the Kunlun Mountains to the south, and the Pamir Mountains and the Tian Shan to the west and north, respectively. The basin is the paradigm of a hyperarid area, where the annual precipitation is less than 50 mm (Fig. 1a) and the potential evapotranspiration is more than 3000 mm, with an annual temperature range more than 30 °C (Ren et al., 1985). As a consequence, the Taklimakan desert, one of the largest sandy deserts of the world, occupies the central part of the basin. Perennial northeasterly and northwesterly winds prevail over the east and west basin respectively (Fig. 1b). These two air currents, converging near the desert's centre at the lower reaches of the Keriya River, create a complex circulation system (Li, 2002) that is clearly reflected in the topography of the sand dunes (Yang et al., 2002). These southward winds raise dust into the air and convey it to highlands on the northern slope of the Kunlun Mountains as Quaternary loess deposits (Fang et al., 2002).

Rivers and streams run from mountain highlands towards the desert basin, giving rise to a number of oases along the mountains foothills, around which the ancient settlements grew and flourished (Fig. 1c). The debut of dwellers in the Tarim Basin in Chinese history was largely through the diplomacy of Zhang Qian (Chang Ch'ien), an imperial envoy of the Han Dynasty. Hence, the period prior to establishment of the Silk Road at the latest first millennial BC is regarded as the prehistoric age. As no water is available in the

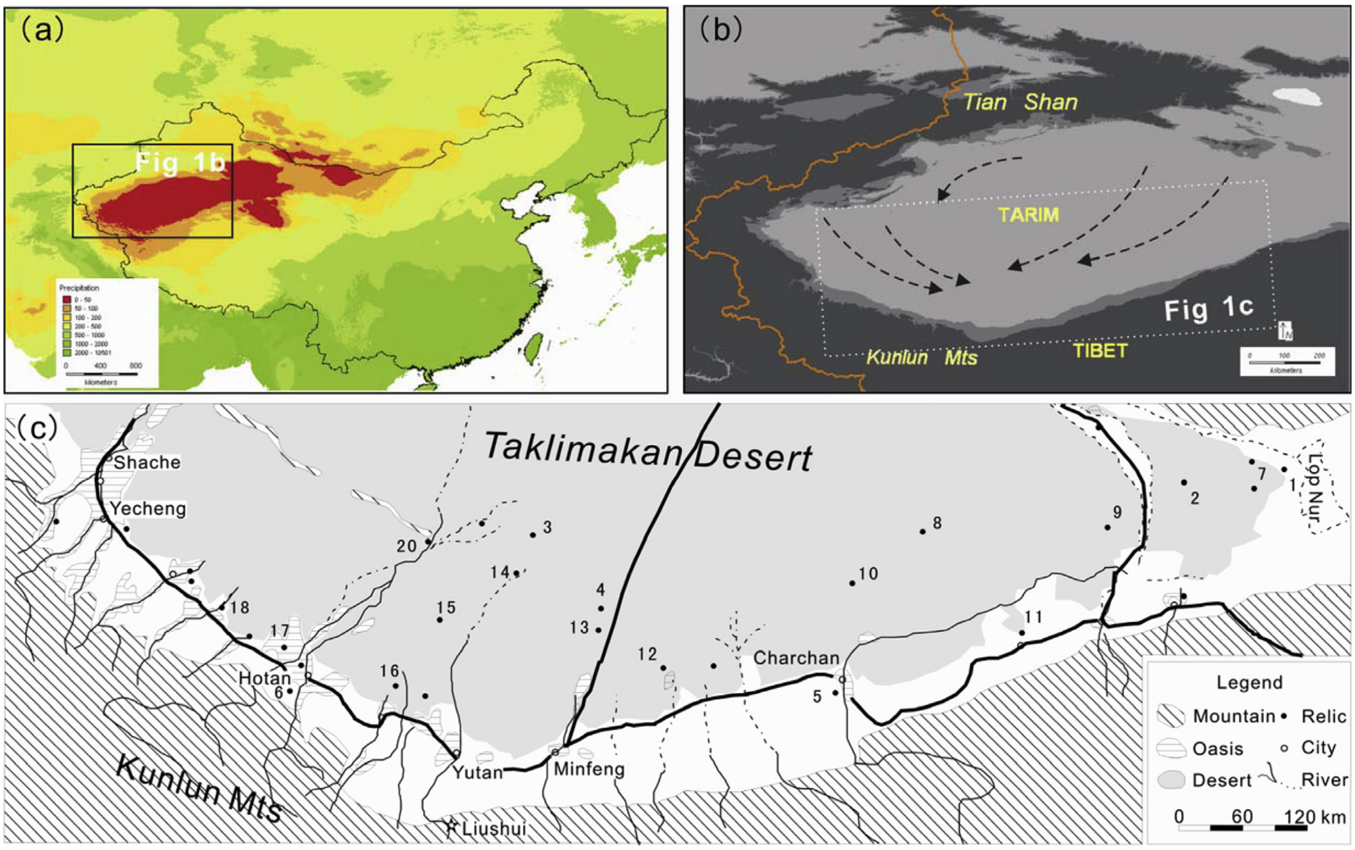

Fig. 1. (a) The mean annual precipitation of East and central Asia; (b) Topographic map of the Tarim basin and its neighboring regions. The dashed lines with arrows represent prevailing wind directions in the basin; (c) Distribution of oases and ancient relics at the southern Tarim basin. **Prior to 3800 BP**: 1 Qäwrighul; 2 Xiaohe; 3 North Keriya; 4 North Niya; **After ~2700 BP and prior to the historical period**: 5 Zaghunluq; 6 Sampula; **Historical period**: 7 Loulan; 8 Miran; 9 Luobuzhuang; 10 Qiemo; 11 Waxxari; 12 Andir; 13 Niya; 14 Kelaton; 15 Dandanwulik; 16 Wucentoti; 17 Yuetegan; 18 Canggui; 19 Pishan; 20 Mazartag.

desert and it is hazardous to cross, human civilizations and communities are restricted to oases around the desert which are fed by water from the surrounding mountains. Since the successful scientific investigations by Sven Anders Hedin and Sir Aurel Stein in the latest 19th century, notable findings of remains in southern Tarim, covering the Bronze Age through to the historical period, have been reported in detail.

2.1. Tarim Basin

There is evidence for human occupation in the southern Tarim Basin dated to ~2000 BP (Barber, 2000; Han, 2008). Since then, several rise–fall cycles of Tarim ancestors are registered by a dozen relict oasis towns in the southern basin. The duration and timing of the prehistoric relics from the southern Tarim Basin are concentrated in two periods, before ~3000 BP and after ~2700 BP.

2.1.1. Before 3000 BP

The earliest human occupation found in the Tarim Basin comes from the area known in Chinese annals as Loulan and Lop Nur in the southeast of the basin, including the Xiaohe and Qäwrighul cemeteries ("Gumugou" in modern standard Mandarin). They, dated to 4000–3800 BP, can be assigned unequivocally to a Bronze Age complex by small bronze ornaments and plaques found in the graves and the quality of the woodworking. These two relics share numerous features, such as timber uprights, use of ephedra, grain baskets, and absence of ceramics (Mallory and Mair, 2008). Lines of evidence from anthropology (Han, 1986), genetics (Li et al., 2010), as well as typological comparison of the funerary goods (Han, 2008), indicate a close affiliation between the two sites and the Andronovo culture that flourished in Siberia. More recently, a Xiaohe-like North Keriya Cemetery has been visited and preliminarily investigated at the lowest reaches of the Keriya River from the interior of the Taklimakan Desert (Zhang, 2009), suggesting the early Bronze Age cultures in the Basin were not constrained at Lop Nur and were distributed in the basin interior during the Early 2nd Millennium BC.

During the 1990s, the North Niya complex, ~43 km north of the Niya site, was investigated. Two convex-edged bronze knives and abundant pottery vessels were collected from the site, not only assigning it to the Late Bronze Age but also registering the connection with other cultures in the basin. The excavators had noted that the forms and decorations of the pottery from the site closely resemble those found on the pointed-bottom straw basket from the Small River and Qäwrighul cemeteries. Due to limited datable materials, its numerical age is still uncertain, but is generally estimated between 3500 and 3000 BP from the features of the relics (Yue and Yu, 1999; Lin, 2006).

2.1.2. After ~2700 BP and prior to historical periods

The Zaghunluq cemetery, spanning the interval from 3000 to 1500 years ago, is representative of the cultural remains during this period. Based on grave forms, funerary goods and radiocarbon dating, the 102 excavated tombs are divided into three cultural phases. Among them, the second phase involves 90 tombs, fully characterizing the culture of the cemetery and dating back to ~2700 to ~1900 years before present (The Museum of the Xinjiang Uygur Autonomous Region et al., 2003). The tombs are mostly rectangular shaft earthen pits, in which the burials were entombed singly, multiply or collectively in secondary burials mostly in a flexed supine position. Burial objects are mainly pottery vessels and wood wares, many of which were used in routine life. Among the vessels, brown pottery coated with black slip is the most distinctive, including finds of vase, kettle, bowl and cup, of which the round-bottomed vessels are most common while flat-bottomed and ring-footed vessels are sparse. Burial objects also include a few stone tools, bone implements, bronze and iron artifacts.

Although relics of historical periods in the southern Tarim Basin has been excavated since the turn of the 20th century and extensively investigated, such as the sites of Niya, Sampula ("Shanpula" in modern standard Mandarin) (The Museum of the Xinjiang Uygur Autonomous Region, 2001), Loulan, etc., the chronological gaps between the prehistoric relics in Tarim basin are still noticeable.

2.2. Northern slope of the Kunlun Mountains

On the southern edge of the Tarim Basin, thick loess blankets the northern slopes of the Kunlun Mountains and also covers cultural remains. About 80 km away from the desert, Liushui cemetery (Fig. 1c) occupies an area of 4000 m^2 on the third terrace of the upper Keriya River in the Kunlun Mountains, ~2850 m above sea level. The entire graveyard with 52 earth pit tombs has been excavated recently and 11 samples from 9 tombs were radiocarbon-dated (Wagner et al., 2011). The results suggest that the whole phase of activity started between 1108 and 893 BC (95% probability range) and finished between 760 and 493 BC. The excavated tombs are all earthen pits with stones piled or enclosed on top, and contain the skeletons of several persons laid on top of one another in layers, commonly reinterred here a long time after their death. The goods with which the graves were endowed are pottery vessels that are all hand-made and are ornamented with incised design. Among burial pottery, sand-red coarse ware predominates, and red or gray ware made of fine clay is rare. Metal ornaments in the Scythian style and necklaces made of variously coloured stone beads are equally common (Xinjiang Archaeological Team Institute of Archaeology, 2006).

Comparing the timing of the relics, the duration of the Liushui cemetery on the Kunlun highland is sufficient to fill the chronological discontinuity between the sites from the southern Tarim Basin, showing a nearly see–saw relation between them (Fig. 2, the data can be found in the Supplementary material Table S1). This pattern raises the question: did any factors exist to influence the distribution of prehistoric relics in the southern Tarim? Analyses on the evolution of historical and modern oases in the study area provide possible information about the driving forces of relic redistribution, i.e., changes in water availability due to climate aridification and/or river realignment (Zu et al., 2003). Whether they impact redistributions of the prehistoric relics can only be determined by a reliable palaeoclimatic reconstruction.

3. Placing prehistoric civilization of the Tarim Basin into a climatic context

Loess deposits covering the Liushui cemetery also record palaeoclimatic signals, providing an opportunity to understand the climatic context of the relics' duration. Section KMA adjacent to the Liushui cemetery was analyzed to identify the palaeoclimate processes during the past 5000 years (Tang et al., 2009). Various conventional proxies, particularly pollen assemblage and grain size, were adopted to reconstruct the palaeoclimate history. Generally, pollen assemblage mirrors regional vegetation; while there are extremely sparse plants in the hyperarid Tarim Basin, pollen deposited in the KMA section mainly reflects vegetation on the highlands, which are dominated by local moisture. For convenience, the A/C ratio (El-Moslimany, 1990) is adopted as a moisture indicator to demonstrate the environmental history. *Artemisia* is an important steppe component, whereas Chenopodiaceae characterizes desert vegetation. Grain sizes of aeolian loess are dominantly controlled by wind intensity and proximity of source desert, linked closely to drought severity in the basin. Therefore, a higher

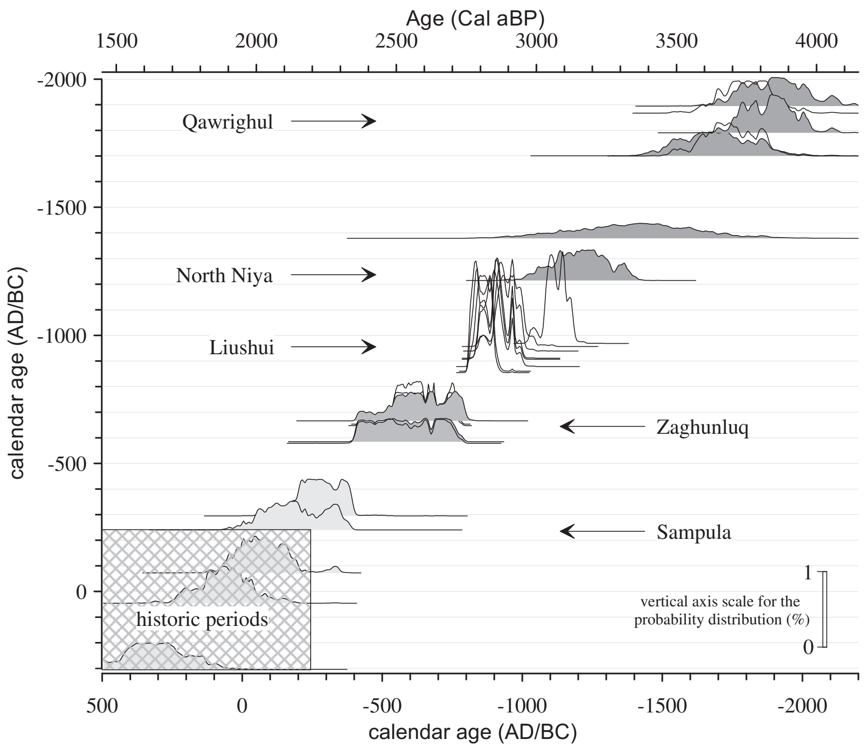

Fig. 2. The duration of the typical relics in the southern Tarim basin. All ages are calibrated to calendar age with reference to the IntCal09 calibration curve (Reimer et al., 2004). The vertical axis scale for the probability distribution curves is presented as an inset at the lower right corner. The vertical position of the calibrated curves is plotted against the midpoint of the calibrated dates with 2σ.

Artemisia/Chenopodiaceae (A/C) ratio of pollen is proposed as a moisture indicator of the Kunlun highlands. Greater mean grain size (Mz) is an indicator of stronger aridity of the southern margin of the basin (Fig. 3).

The records provide a multi-decade-resolution history of climate. During the past 5000 years, pollen preserved in the section reveals a slightly drying trend with significant moisture fluctuations on the Kunlun highland. A/C ratios greater than 1 suggest that, on the highland, the interval between 3000 and 2600 cal BP is the moistest period. The grain size records from the same samples suggest a nearly opposite scene in the southern margin of the Taklimakan Desert. A gradual decrease of the mean grain size (Mz) record reflects a slight decrease of arid strength in the Taklimakan Desert margin with the most significant increase in aridity at 3000–2600 cal BP, indicated by the greater Mz value.

Comparison of grain size to A/C ratio of pollen suggests that periods with stronger aridity in the south margin of the desert are coincident with increasing moisture condition at the section locality. This link can be verified by NCEP/NCAR reanalysis data of 20th century climate (Kistler et al., 2001). Above the southern Tarim Basin and the northern slope of Kunlun Mountains, the precipitation mainly depends on the vertical air velocity at 1000–300 hPa (Feng et al., 2005). The NE and NW winds, converging in the southern basin, are too dry to form rain; they move southward and recharge moisture from the mountains, and then transform to clouds and rain as a result of upslope motions.

The KMA records, showing the changes in moisture condition with multi-decade resolution, provide a climatic background for the prehistoric archaeological records both from the southern Tarim Basin and the Kunlun highlands (Fig. 3). In the basin, the

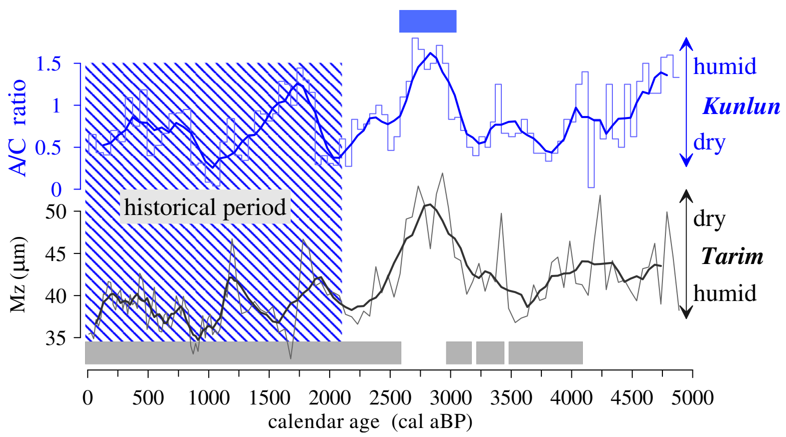

Fig. 3. South Tarim, Kunlun highland paleoclimate records and the duration of the relic finds. The solid curve is 5-point smoothed data and the wet and dry conditions both in the Tarim basin and on the Kunlun highland are indicated by arrows (Tang et al., 2009). The durations of the relics in the basin are marked by gray bars, and those of the Liushui cemetery are marked by diagonal hachures.

duration of the earliest relics, such as the Xiaohe and Qäwrighul cemeteries around 3800 cal BP, was characterized by low sand content in the KMA records that indicate a relatively wet basin, consistent with the highest level of the Bosten Lake during the Holocene (Wünnemann et al., 2006). Later, the North Niya complex (~3500–3000 cal BP) and the Zaghunluq cemetery (mainly centered at 2700–1900 cal BP) also correlated to a period with low sand content in the KMA records, implying a weaker storm activities and increased moisture availability in the basin. On the highland, the environment when the Liushui cemetery was built (~3000–2600 cal BP) was characterized by the highest A/C ratios of the entirely section, with increases of mesophytic herbs such as Leguminosae and Ranunculaceae in the KMA records, indicating a wet period on the Kunlun highland. At the same time, grain size is also the coarsest in the section, showing that dry conditions prevailed in the basin. Juxtaposition of the KMA climatic proxies, together with the relics' duration, shows an unexpected but reasonable scene: whether on the highland or in the basin, the prehistoric relics occur in wet palaeoclimate conditions.

Moreover, taking into account the climatic context, the spatial and temporal distribution of the relics from southern Tarim probably reveals a pattern of ancient migrations under environmental pressures. When stronger winds prevailed in the basin and aridity increased, the ancient inhabitants migrated to the wetter Kunlun highland, where rivers originated and rain was enhanced due the stronger upslope air motion. During the periods of weak wind in the basin, the highland turned relatively dry, and populations migrated from the highlands to oases in the southern basin. It seems possible that the anti-phased moisture changes between the basin and the highland determine the see–saw distribution pattern of ancient human occupations.

4. Cultural evolution during migration

Typological comparison of the excavated potteries provides further confidence of cultural linkages between the relics (Fig. 4). Archaeologists had alluded to the similarity of the forms and decorations between the potteries collected at the North Niya and the pointed-bottom straw basket recovered at the Xiaohe and Qäwrighul cemeteries, implying some possible links between the two sites (The Japanese-Chinese Joint Research of the Niya Site, 1999; Yue and Yu, 1999). The excavators pointed out that the forms of potteries from Liushui cemetery are exactly like those found in the Zaghunluq cemetery (Xinjiang Archaeological Team Institute of Archaeology, 2006), and Han (2008) further suggested, based on topological comparison of potteries, that the Liushui cemetery finds are culturally affiliated with those found in the North Niya site (Fig. 4). All these similarities suggest cultural connection between them.

In addition, the cultural sequences, reflected by the potteries and other utensils, suggest a progressive evolution of prehistoric culture in the Basin. Trade, for example, became a major element in economic life. No noticeable trade goods were found from the North Niya site, whereas jade ware was excavated from the Liushui cemetery which might have come from a neighboring area. In the Zaghunluq cemetery, large amounts of silks and lacquers were unearthed that were likely imported from Central China.

During the same period, metallurgical technology also increased continuously. Only bronze knives were found in the North Niya site, and bronze works accompanied by sporadic copper, gold and iron wares at the Liushui cemetery. In the Zaghunluq cemetery, bronze, gold and iron wares achieved a particularly significant stage with the occurrence of metal ornaments, rather than merely as production equipment. During the migration of people between both the basin and the highland, cultural complexities increased gradually from ~3800 BP to the historical period without significant absences or collapses, despite the fluctuating climatic conditions. This implies that ancient cultures can succeed and develop through periods of significant migration.

If climate does drive cultural evolution as some authors proposed, it could be expected that the apparent drying of the southern Tarim would have resulted in a significant reduction of social complexity. However, the cultural complexities show a successive, gradually progressive sequence and thus highlight three implications. First, population redistribution is a voluntary and effective strategy for ancient Tarim people to survive climate change. Second, environmental pressures have limited influences on civilization evolution, even in fragile habitats like the hyperarid Tarim and during prehistoric periods. Third, a unidirectional relationship from climate change to human response may not always emerge and more caution is needed to assess the influences of environmental change to civilization.

Fig. 4. Typological comparisons of the excavated potteries from the southern Tarim.

5. Caveats and future work

The palaeoclimatic and archaeological data strongly suggest a temporal correlation between the aridity changes and human redistributions, and we tentatively conclude that moisture change, although not the sole reason, is an important explanation for relic distributions in the hyperarid Tarim. The data, however, do not have the ~10-a resolution required to firmly establish this link. This could be shown by detailed investigation of temporal correspondence between cultural transitions, distribution of relics, and climatic-driven palaeoecological changes in a credible high-resolution time framework.

If one says that climate amelioration or deterioration substantially causes cultural rise or fall, this need to be more to say than just climate changes matches well with cultural stages in a temporal dimension. Interpretation of the linkage between climate and culture in China during the historical periods therefore remains an important challenge to palaeoclimate scientists. For instance, collapses of the Tang, Yuan, and Ming Dynasties match well with weak summer monsoon from reconstructed palaeoclimate sequences based on various proxies, and the flourishing of the early North Song Dynasty correlates with summer monsoon peak (Yancheva et al., 2007; Zhang et al., 2008). However, the role of weak summer monsoons occurring in the last peak of dynastic China (Spence, 1999), the Prosperous Era of Emperor Kangxi-Qianlong, next to the collapse of the Ming Dynasty, is purposely omitted. Selective evidence may influence perception of the key role of climate on civilization.

Cause-effect hypotheses, while seductive in their simple explanation of how ancient cultures responded to climate change, do not do justice to the complexity of the climate-culture problem or to the full range of cases. For a credible cause-effect relationship between climate change and human evolution, Behrensmeyer (2006) proposed three criteria: a clear definition of "synchronous", the mechanism for transmitting climatic cause to evolutionary effect, and the coinciding climatic events based on multiproxies. When it comes to relationships assessing the link between climate and culture, the universal and testability of the mechanism should be appended to the criteria to exclude selected cases.

Acknowledgments

We thank Professor Yan Shun, Yang Shiling, Yu Zhiyong and Dr Alijiang Aisha for helpful discussion and constructive comments, and also thank An Jutian, Matkasm, and Azis for field assistance. We also thank the two anonymous referees for comments that improved the quality of the paper. This research was supported by the National Basic Research Program of China (973 Program) (No. 2010CB950204), the Strategic Priority Research Program of the Chinese Academy of Sciences (No. XDA05120204), and the National Science & Technology Pillar Program (2009BAC54B05).

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.quaint.2013.01.021.

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