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LEAD ISOTOPIC ANALYSES OF COPPER ORES IN THE EARLY BRONZE AGE CENTRAL HEXI CORRIDOR, NORTH-WEST CHINA*

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This paper explores the possible provenance of ores employed for metallurgical production during the Early Bronze Age in the central Hexi Corridor of north-west China. In total, 78 pieces of copper (Cu) ore samples were collected from five Early Bronze Age sites and one Cu deposit site (the Beishantang Cu deposit) in the Heihe River region of the central corridor. These sites were dated to the late Machang (4100–4000 BP*), Xichengyi (4000–3700* BP*), Qijia (4000–3600* BP*) and Siba (3700–3400* BP*) cultures. After comparing with published lead (Pb) isotopic data from other possible Cu deposits in north-west China, the results show that the Cu ores collected from the Early Bronze Age sites were most likely derived from the adjacent Beishan Cu deposit. More intriguingly, for the first time in Hexi Corridor, a dozen Cu ores were discovered containing highly radiogenic Pb. Though fundamentally different from those in the Central Plains, they illustrate a possible new type of Cu used in Bronze Age western China, and the first-hand materials are significant for further understanding the provenance of raw metals for metallurgical production in the prehistoric Hexi Corridor.*

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INTRODUCTION

Whilst the origin and spread of bronze metallurgy in prehistory have been widely discussed and debated (Branigan 1982; Mei and Colin 1999; Niederschlag *et al*. 2003; Cooper *et al*. 2008; Hanks and Doonan 2009; Roberts *et al*. 2009; Radivojević *et al*. 2010; Ling *et al*. 2013; Courcier 2014; Pollard *et al*. 2018), a key consensus has gradually emerged in recent years that in the eastern extreme of Eurasia, Bronze Age China evidenced a remarkably different pattern from that of the other regions (Pollard *et al*. 2017; Rawson 2017; Zhang *et al*. 2019). Disentangling the role of metallurgy in the development of early dynastic China requires a further understanding of the routes as well as the mechanism through which the imported technology fitted into the new host environment. In this context, the Hexi Corridor is again at the heart of the discussion (Fig. 1). The corridor performed a vital intersection linking central China (or the Central Plains) to Xinjiang and further west over several millennia, and scholars often assume it to be one of the most critical routes through which a variety of major prehistoric materials passed through, for example, millet (Wang *et al*. 2017; Dong *et al*. 2017a), painted pottery from east to west, or wheat (e.g., Flad *et al*. 2010; Liu *et al*. 2017) and metallurgy (Mei 2003; Zhang

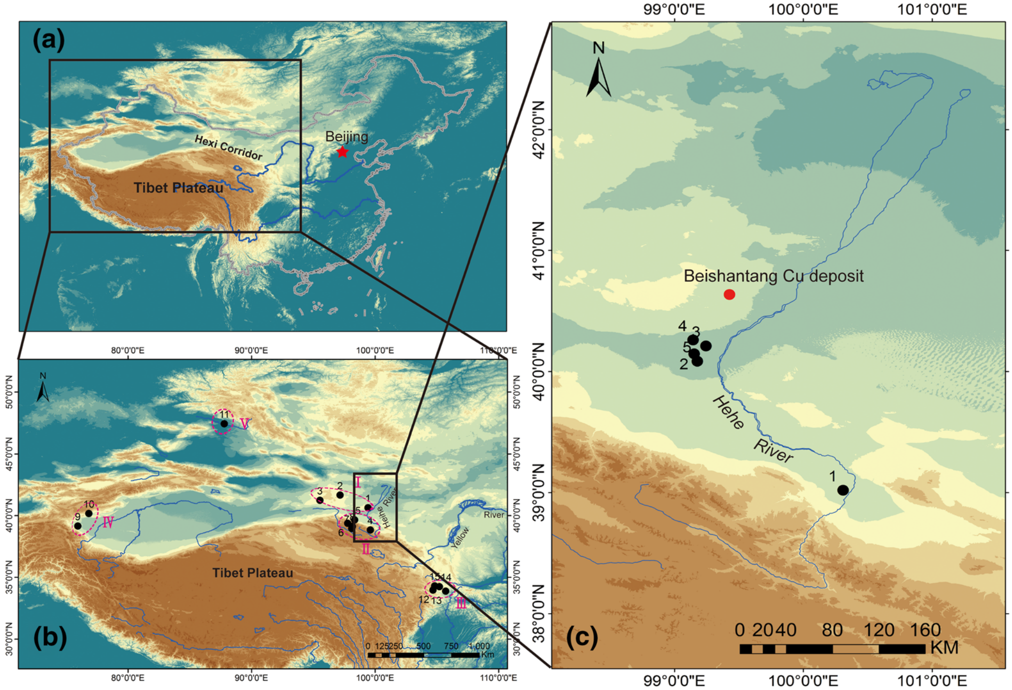

Figure 1 *(a) Study area and sampling points in China; (b) I–IV represent the Beishan, North Qilian, Xinjiang and West Qinling Cu deposits, respectively; 1–15 represent the small Cu deposits: 1, Baishantang; 2, Gongpoquan; 3, Huaniushan; b-II: 4, Shijuli; 5, Xiaoliugou; 6, Huashugou; 7, Dadonggou; 8, Diaodaban; b-III: 9, Tamu-Kalan; 10, Hosh Braque; 11, South Altay; b-IV: 12, Pidipo; 13, Bijiashan; 14, Luoba; and 15 Xialadi; and (c) 1–5 represent the sampling points: 1, Xichengyi; 2, Ganggangwa; ,3 Huoshiliang; 4, Erdaoliang; and 5, Yigediwonan2. [Colour figure can be viewed at wileyonlinelibrary.com]* *et al*. 2017) from west to east. It is within this region that archaeologists discovered the oldest bronze object so far in China (*c*.5000–4500 BP at the Majiayao site; GPCRT *et al*. 1984). A few copper (Cu) ores have also been reported from cultural layers in the sites of Huoshiliang and Ganggangwa, which can be dated to *c*.4100 BP in the Hexi Corridor (Dodson *et al*. 2009). One of the most challenging issues is to identify the provenance of the raw metals for metallurgical production in the Hexi Corridor, especially during the Early Bronze Age. Its archaeological significance cannot be overestimated, because the answer to this question can be directly related to broader archaeological questions concerning not only the circulation of metal within the Hexi Corridor itself but also the mechanism through which the spread of metallurgy into central China was effected (by the movement of raw metals, finished objects, people or ideas).

The paper presents 78 fresh Pb isotopic data for Cu ore samples collected from five key Bronze Age sites and one Cu deposit (the Baishantang Cu deposit, which belongs to a part of the Beishan Mountain Cu deposit) in the Heihe (Black) River area within the central Hexi Corridor. We argue that the overall data set can be divided into at least three groups, and comparative studies with geological data suggest that the largest group of samples can only be matched to the Beishan Cu deposit. The second group of data is surprisingly highly radiogenic. What is more interesting is that this group is clearly different from the highly radiogenic Pb in the bronzes of the Central Plains (Jin 2008; Liu *et al*. 2015, 2018a, 2018b; Sun *et al*. 2016, 2018; Jin *et al*. 2017). Whilst pinpointing its exact geological source is not yet possible, this discovery will undoubtedly form a preliminary advance in the debate about the sources of highly radiogenic Pb in north-west China.

Study area

The Hexi Corridor (92°21′–104°45′E, 37°15′–41°30′N) (Fig. 1 a, b) in north-west China is located in a strategic area of the Silk Road. It is a 1000-km narrow corridor between the North Mountains (including the Mazong, Heli and Longshou mountains) and the South Mountains (including the Qilian and A-erh-chin mountains). Three main inland rivers, including the Shule, Heihe and Shiyang, flow from south to north in the region. The annual temperature ranges from 2.5 to 17.5°C; annual precipitation ranges from 50 to 800 mm. This special geographical position makes it an important channel for cultural exchange between western and eastern Eurasia. The Heihe River region (98°00′–101°30′E, 38°15′–41°30′N) is located in the middle of the Hexi Corridor (Fig. 1, c), which is the primary inland river in the region. It runs for 800 km from Ejina Banner in the north and extends to the Qilian Mountains in the south. The drainage area is about 13×10^4 km^2. The sequence of prehistoric cultures in the Hexi Corridor established by previous studies (Chen *et al*. 2014; Zhou *et al*. 2016; Dong *et al*. 2017b; Yang *et al*. 2019) includes the Majiayao (5000–4600 BP), Banshan (4600–4300 BP) and Machang (4300–4000 BP) phases, as well as the Qijia (4000–3600 BP), Xichengyi (4000–3700 BP), Siba (3700–3400 BP), Shajing (2800–2400 BP) and Shanma (3000–2400 BP) cultures. Prehistoric cultures in the Heihe River region mainly include the Machang, Xichengxi, Qijia and Siba. The geographical locations of the targeted sites in this study are strategically important as they are well connected in multiple directions in the central Hexi Corridor via the Heihe River.

MATERIALS AND METHODS

A total of 78 samples of Cu ore (Cu oxides) were collected from five archaeological sites and one Cu deposit site (Table 1). They included 15 pieces from Ganggangwa, 16 from Huoshiliang, 31

Table 1 *Ore samples collected in five Bronze Age sites in the Heihe River region*

	Number of samples	
Site	*Xichengyi and Qijia (4000–3700 BP)*	*Siba (3700–3500 BP)*
Ganggangwa	15	
Huoshiliang	16	
Xichengyi	23	8
Erdaoliang	5	
Yifediwonan2	5	
Baishantang Cu deposit	6	
Total	78	

from Xichengyi, five from Erdaoliang and five from Yigediwonan2; the other five Cu ore samples were collected from the Baishantang Cu deposit site. Except for the six ore samples associated with the Siba culture within the Xichengyi site, the other 66 were all unearthed from the archaeological layers of the Xichengyi and Qijia cultures. Their chronology was primarily based on the stratigraphic sequence, the identity of the coexisting pottery (Fig. 2) and radiocarbon dates (in total there were 26 radiocarbon dates from Xichengyi site, 4085–3480 BP) (Zhang *et al*. 2015).

Methods

First, to identify the composition of the ore, a scanning electron microscope (SEM; JSM6480LV, Japan Electron Optics Laboratory) and an energy-dispersive spectrometer (EDS; Noran System six, Thermo Electron Corp.) were used. Samples were carefully polished by water sandpaper from coarse to fine in order to meet the requirement of the SEM-EDS. The analytical parameters were set up as 20 kV for the acceleration voltage and 50 s for live measurements. Since the primary objective in this process was the quick identification of the nature of the ores, we used the preset single-element standards for quantification.

Second, Pb isotopic analyses were conducted using the thermal ionization mass spectrometer (TIMS) assembly in the Analytical Laboratory of BRIUG. An ISOPROBE-T TIMS assembly (No. 7734) was used to measure all 78 ore samples. The testing process was in strict accordance with the ‘Determinations for Isotopes of Lead, Strontium and Neodymium in Rock Samples’ (GB/T 17672-1999), which is formulated by the People’s Republic of China (PRC) National Standard. The final result of error was correct to 2σ.

RESULTS

The results of the SEM-EDS show that, among the 72 Cu ore samples collected from the five archaeological sites, 57 belonged to Cu oxides and the other 15 were polymetallic minerals containing Cu, Pb, As and Sn (see Tables S1 and S2 in the additional supporting information). Five of the six samples collected from the Baishantang Cu deposit were Cu oxide ore; the last one was a polymetallic mineral with components of Cu, Zr and Ba.

The results of the Pb isotope measurements are shown in Table 2. The mean ^{208}Pb/^{204}Pb, ^{207}Pb/^{204}Pb and ^{206}Pb/^{204}Pb were 38.29853, 15.63865 and 18.68708, respectively, with very

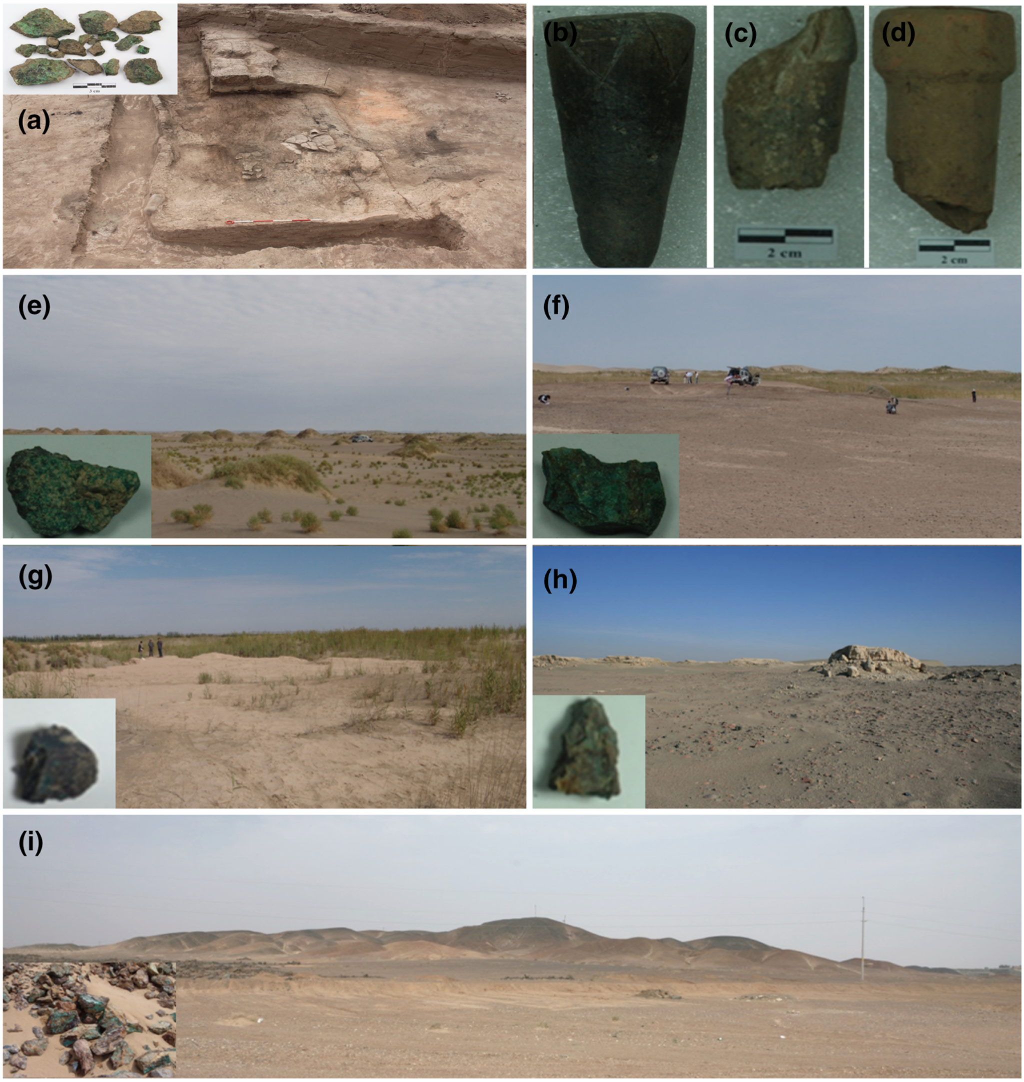

Figure 2 *Appearance of the sampling sites and the objects unearthed from the sites. Images show the appearance of sites; insets show the objects unearthed from those sites: (a) adobe building at Xichengyi; (b–d) blast pipes unearthed from Xichengyi; (e) Ganggangwa; (f) Huoshiliang; (g) Erdaoliang; (h) Yigediwonan2; and (k) Baishantang Cu deposit. [Colour figure can be viewed at wileyonlinelibrary.com]*

small variance. Interestingly, a substantial number of samples ($n = 12$) collected from Ganggangwa, Xichengyi and Yigediwonan2 contained Pb isotopes that were certainly highly radiogenic (Table 2), the highest $^{206}Pb/^{204}Pb$ of which was 25.383.

Provenance of the ore

Nearly 80% of the ore samples (57/72) collected from the Ganggangwa, Huoshiliang, Xichengyi, Erdaoliang and Yigediwonan2 sites were Cu oxide ore, whereas only 20% of the ore samples (15/

Table 2 *Results of Pb isotopes in 78 Cu ore samples*

Laboratory number	*Site*	$^{208}Pb/^{204}Pb$	*Error*	$^{207}Pb/^{204}Pb$	*Error*	$^{206}Pb/^{204}Pb$	*Error*
GGW21	Ganggangwa	38.512	0.006	15.681	0.002	18.415	0.003
GGW22	Ganggangwa	38.250	0.003	15.601	0.001	18.389	0.002
GGW23	Ganggangwa	38.245	0.002	15.587	0.001	18.643	0.001
GGW24	Ganggangwa	38.175	0.004	15.596	0.002	18.332	0.002
GGW25	Ganggangwa	38.394	0.003	15.585	0.001	18.984	0.001
GGW26	Ganggangwa	38.588	0.005	15.657	0.002	19.146	0.002
GGW27	Ganggangwa	38.479	0.005	15.673	0.002	18.447	0.002
GGW28	Ganggangwa	38.081	0.002	15.594	0.001	18.292	0.001
GGW29	Ganggangwa	37.863	0.004	15.584	0.002	18.278	0.002
GGW30	Ganggangwa	38.260	0.004	15.613	0.002	19.131	0.002
GGW31	Ganggangwa	38.158	0.004	15.582	0.002	18.454	0.002
GGW32	Ganggangwa	38.316	0.005	15.756	0.002	22.649	0.003
GGW33	Ganggangwa	38.208	0.003	15.591	0.001	18.375	0.002
GGW34	Ganggangwa	37.603	0.004	15.532	0.002	17.995	0.002
GGW35	Ganggangwa	38.039	0.003	15.570	0.001	18.295	0.002
HSL21	Huoshiliang	38.060	0.003	15.596	0.001	18.257	0.001
HSL22	Huoshiliang	38.257	0.003	15.650	0.001	18.287	0.001
HSL23	Huoshiliang	38.202	0.003	15.581	0.001	18.455	0.002
HSL24	Huoshiliang	38.618	0.005	15.703	0.002	18.446	0.003
HSL25	Huoshiliang	38.098	0.003	15.600	0.001	18.259	0.002
HSL26	Huoshiliang	38.054	0.004	15.600	0.001	18.198	0.002
HSL27	Huoshiliang	37.000	0.003	15.531	0.001	17.265	0.001
HSL28	Huoshiliang	38.076	0.004	15.584	0.001	18.344	0.002
HSL29	Huoshiliang	38.327	0.006	15.622	0.002	18.454	0.003
HSL30	Huoshiliang	38.374	0.005	15.633	0.002	18.536	0.003
HSL31	Huoshiliang	38.217	0.005	15.593	0.002	18.419	0.002
HSL32	Huoshiliang	38.240	0.003	15.599	0.001	18.712	0.002
HSL33	Huoshiliang	38.220	0.003	15.598	0.001	18.750	0.001
HSL34	Huoshiliang	38.233	0.006	15.597	0.002	18.654	0.003
HSL35	Huoshiliang	38.252	0.007	15.599	0.003	18.538	0.003
HSL93	Huoshiliang	38.615	0.004	15.597	0.002	18.774	0.002
12JEK01	Erdaoliang	38.595	0.006	15.694	0.003	18.439	0.003
12JEK02	Erdaoliang	38.127	0.004	15.618	0.002	18.244	0.002
12JEK03	Erdaoliang	38.095	0.003	15.605	0.001	18.233	0.001
12JEK04	Erdaoliang	38.171	0.003	15.622	0.001	18.255	0.001
12JEK05	Erdaoliang	38.106	0.003	15.566	0.001	18.378	0.002
12JYK01	Yigediwonan2	38.397	0.004	15.653	0.002	18.445	0.002
12JYK02	Yigediwonan2	38.070	0.004	15.600	0.002	18.224	0.002
12JYK03	Yigediwonan2	38.246	0.002	15.692	0.001	20.523	0.002
12JYK04	Yigediwonan2	38.179	0.002	15.582	0.001	18.533	0.001
12JYK05	Yigediwonan2	38.340	0.003	15.594	0.001	18.585	0.002
10ZHK1	Xichengyi	38.537	0.004	15.657	0.001	18.638	0.002
10ZHK2	Xichengyi	38.289	0.004	15.635	0.002	18.678	0.001
10ZHK3	Xichengyi	38.387	0.003	15.633	0.001	18.652	0.001
10ZHK4	Xichengyi	38.475	0.003	15.638	0.001	18.461	0.001
10ZHK5	Xichengyi	39.391	0.003	15.755	0.001	19.116	0.001
10ZHK6	Xichengyi	38.156	0.002	15.640	0.001	18.604	0.001

(*Continues*)

Table 2 *(Continued)*

Laboratory number	*Site*	$^{208}Pb/^{204}Pb$	*Error*	$^{207}Pb/^{204}Pb$	*Error*	$^{206}Pb/^{204}Pb$	*Error*
10ZHK7	Xichengyi	38.344	0.004	15.625	0.002	18.457	0.002
10ZHK8	Xichengyi	38.077	0.005	15.579	0.002	18.189	0.002
10ZHK9	Xichengyi	38.250	0.006	16.047	0.003	25.383	0.003
10ZHK10	Xichengyi	38.532	0.003	15.660	0.001	18.691	0.001
10ZHK11	Xichengyi	38.348	0.004	15.666	0.002	19.799	0.002
10ZHK12	Xichengyi	38.428	0.005	15.677	0.002	19.288	0.002
10ZHK13	Xichengyi	38.478	0.004	15.644	0.002	18.628	0.002
10ZHK14	Xichengyi	38.535	0.006	15.652	0.002	18.541	0.002
10ZHK15	Xichengyi	37.277	0.002	15.470	0.001	17.578	0.001
10ZHK16	Xichengyi	38.444	0.004	15.638	0.002	18.554	0.002
10ZHK17	Xichengyi	38.323	0.003	15.718	0.001	20.486	0.002
10ZHK18	Xichengyi	38.383	0.002	15.629	0.001	18.411	0.001
10ZHK19	Xichengyi	38.324	0.003	15.613	0.001	18.383	0.001
10ZHK20	Xichengyi	38.271	0.006	15.619	0.002	18.385	0.002
10ZHK21	Xichengyi	38.445	0.004	15.652	0.001	18.402	0.001
10ZHK22	Xichengyi	38.392	0.003	15.634	0.001	18.402	0.001
10ZHK23	Xichengyi	38.368	0.003	15.627	0.001	18.414	0.001
11ZHK1	Xichengyi	38.590	0.006	15.644	0.003	18.351	0.003
11ZHK2	Xichengyi	38.988	0.003	15.852	0.001	18.447	0.002
11ZHK3	Xichengyi	38.559	0.004	15.652	0.002	18.342	0.001
11ZHK4	Xichengyi	38.561	0.003	15.673	0.001	18.505	0.002
11ZHK5	Xichengyi	38.911	0.004	15.828	0.002	18.428	0.002
11ZHK6	Xichengyi	38.516	0.003	15.672	0.001	19.273	0.002
11ZHK7	Xichengyi	38.526	0.003	15.724	0.001	19.603	0.002
11ZHK8	Xichengyi	38.543	0.006	15.661	0.002	19.038	0.003
BST1	Baishantang	38.040	0.003	15.594	0.001	18.181	0.002
BST2	Baishantang	38.179	0.003	15.624	0.001	18.329	0.001
BST3	Baishantang	38.082	0.005	15.613	0.002	18.171	0.002
BST4	Baishantang	38.157	0.004	15.628	0.002	18.238	0.001
BST5	Baishantang	38.423	0.006	15.717	0.002	18.260	0.003
BST6	Baishantang	38.416	0.003	15.714	0.001	18.254	0.001
Mean	38.29853		15.63865		18.68708		
Variance	0.09589		0.005649		1.027949		

72) were polymetallic minerals with oxides of Cu, Pb, As and Sn. That means that craftspeople in the central Hexi Corridor relied predominately on the Cu oxide ore for smelting.

To trace the provenance of these ores, we carried out a comprehensive comparative study between the 78 sets of Pb isotopic data in the current paper and those published for the adjacent regions that could be the original source of the Cu ores, including the Beishan, North Qilian and West Qinling mountains and Xinjiang Cu deposits (Figs 1 and 3). In spite of a certain level of overlapping in the Pb isotopes, these Cu sources appeared to be largely distinguishable from one another, which created a crucial basic map for provenance studies on raw Cu. As shown in Figures 3 (b–d), only 3%, 15% and 14% of the Cu ores fell into the areas defined by the Pb isotopic data of the North Qiliang and West Qinling mountains and Xinjiang Cu deposits, respectively. The major body of data appeared fairly consistent with the pattern of the Beishan Cu

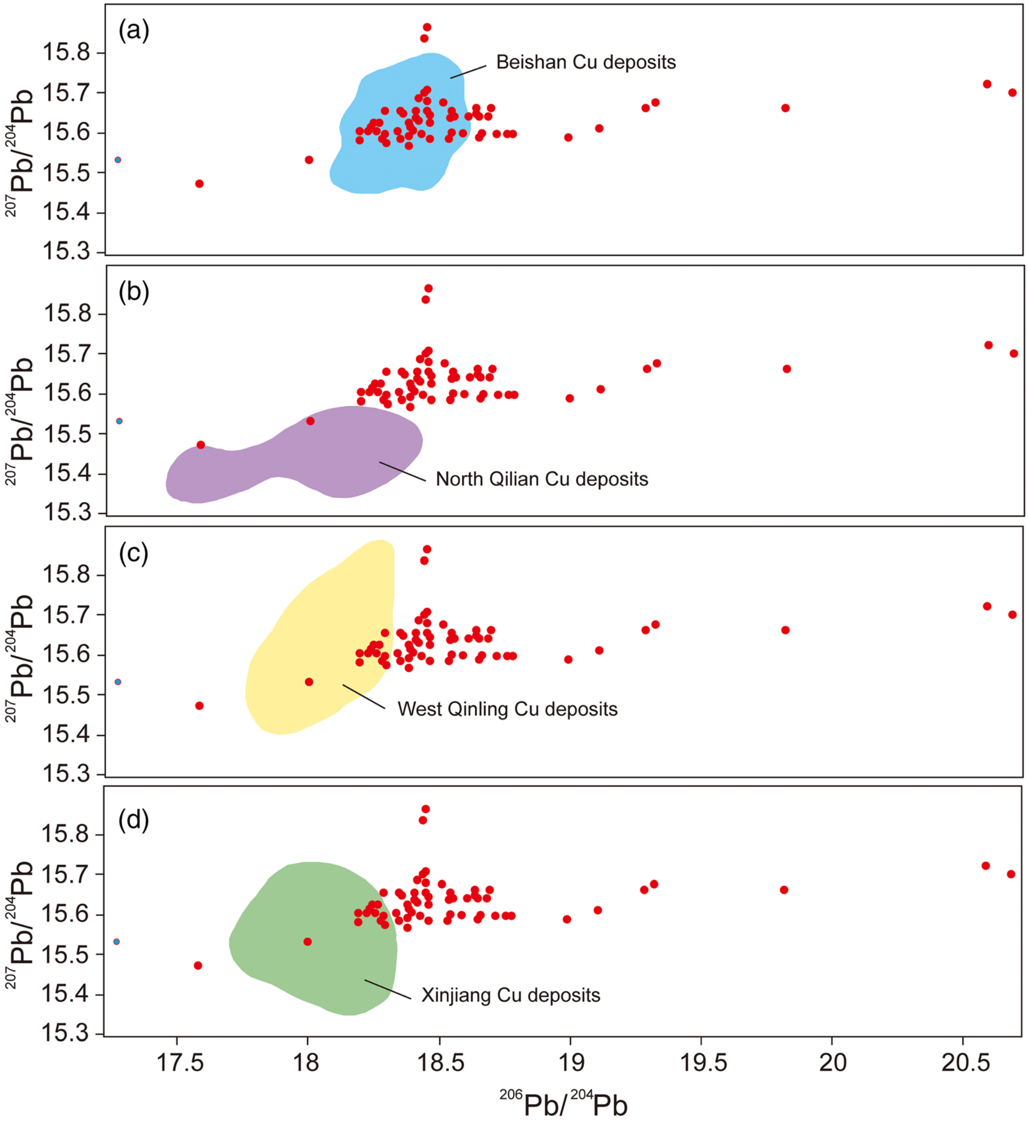

Figure 3 *^{206}Pb/^{204}Pb versus ^{207}Pb/^{204}Pb diagram for Cu ores collected from five archaeological sites and Cu deposits in north-west China: (a) ore samples versus the Beishan Mountain Cu deposit (Jiang et al. 2002; Cao et al. 2008); (b) ore samples versus the North Qilian Mountain Cu deposit (Zhou and Yue 1997; Zhou and Zhou 2000; Zhao et al. 2002; Mao et al. 2003; Song et al. 2003); (c) ore samples versus the West Qinling Mountain Cu deposit (Kuang and Liu 2005; Li and Wang 2006); and (d) ore samples versus the Xinjiang Cu deposit (Xiao 2009). [Colour figure can be viewed at wileyonlinelibrary.com]*

deposits. Geographically, this makes more sense as the Beishan Cu deposits were closest to the sites, and the other three were significantly further away (Fig. 1). For instance, the West Qinling Mountain and Xinjiang Cu deposits were over 800 km further away from the archaeological sites than the Beishan Mountain Cu deposit. This comparison suggested that the Beishan Cu deposits were the most likely source for the Cu ores sampled in the study. In addition to the group of data that could be attributed to the Beishan Cu deposits, at least two other groups identified by this study remained unprovenanced. One is the highly radiogenic Pb (see below); the other included those with very low ^{206}Pb/^{204}Pb (17.2–17.6). So far, only the Pb North Qilian Cu deposits could potentially be matched to such low values.

Highly radiogenic Pb isotopes

In fact, this is not the very first time that archaeologists have discovered highly radiogenic Pb in the Hexi Corridor. Dodson *et al.* (2013) reported one slag sample (Ganggangwa 3S) showing extremely high ^{206}Pb/^{204}Pb (59.081), ^{207}Pb/^{204}Pb (17.403) and ^{208}Pb/^{204}Pb (40.940). This sample unfortunately did not stimulate further debate as to where it came from, nor how it could be associated with those samples recovered from the Central Plains. This is presumably because a single Pb isotopic measurement cannot fit into the mainstream method of comparing Pb isotopes, which requires at least a group of data plotted in two *x*–*y* scatters. They normally form a linear regression and the slope can be informative about the geological history of the ore deposits. In addition, the Pb isotopic data from this slag sample were completely different from the range of radiogenic Pb isotopes in the Shang bronzes (^{206}Pb/^{204}Pb = 19.00–25.00; ^{207}Pb/^{204}Pb = 15.75–17.25; ^{208}Pb/^{204}Pb = 39.0–47.0; Liu *et al.* 2018a, 2018b).

Consequently, the new data in the present paper confirmed the presence of highly radiogenic Pb and also significantly extended the discussion. Generally, the ultimate reason for the increase in these Pb isotopes is the presence of uranium (U) and thorium (Th) together with the Pb-bearing minerals. It was first discovered in the late Shang bronzes in the 1980s, with ^{206}Pb/^{204}Pb > 19–20 (Jin 1987; Jin *et al.* 2017), and it triggers a new debate about the source of this special Pb isotopic signature (see below).

As shown in Figure 4, the highly radiogenic Pb discovered in the Hexi Corridor is vastly different to that which is commonly encountered in the Central Plains. The slope of ^{206}Pb/^{204}Pb

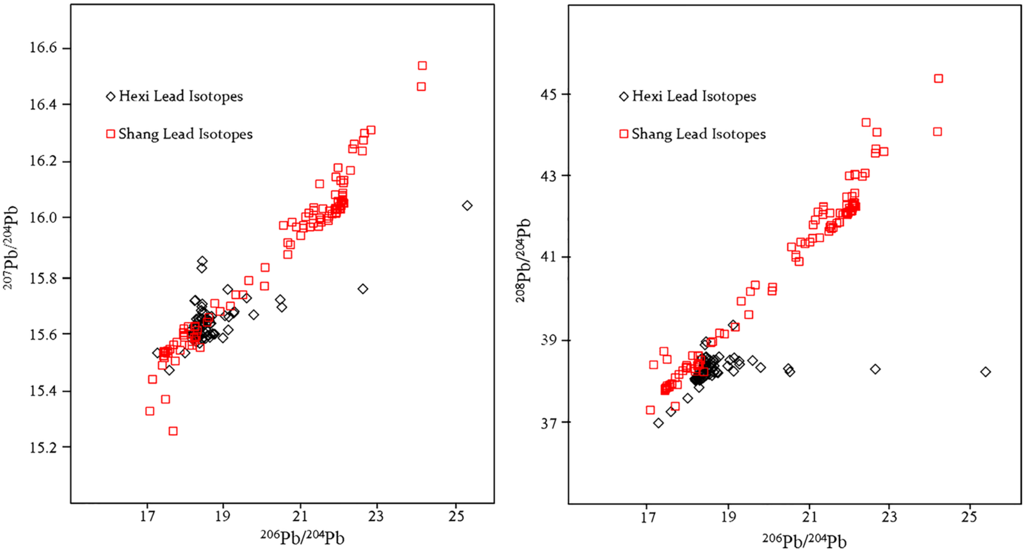

Figure 4 *Comparing the Pb isotopic data between the Hexi Corridor and the Central Plains in Shang, China (Shang Pb isotope data are from Bagley 1987). [Colour figure can be viewed at wileyonlinelibrary.com]*

versus ^{207}Pb/^{204}Pb in the Hexi data is obviously lower than that of the central Chinese Shang data. This demonstrates that whilst ^{206}Pb in the ore samples of Hexi is comparable with that of the Shang bronzes, ^{207}Pb, which is ultimately derived from the ^{238}U over geological time, is less in the Hexi samples than in the Shang bronzes. A further implication that can be drawn is that the geological settings for these two types of highly radiogenic Pb are completely different. This is reinforced by the data of ^{208}Pb (Fig. 4). One defining feature for the highly radiogenic Pb in the Shang bronzes is that all three radiogenic Pb isotopes are higher (^{206}Pb, ^{207}Pb and ^{208}Pb) than in common Pb. Being clearly different, the Hexi Cu ores are only radiogenic in terms of U-derived Pb isotopes (^{206}Pb and ^{207}Pb), but the Th-derived (^{208}Pb) is almost indistinguishable from that in common Pb, as demonstrated by the ^{208}Pb/^{204}Pb. The absence of the Th-derived Pb isotope ^{208}Pb in the ore samples of the Hexi Corridor adds further evidence to the argument that their geological setting is not the same as that of the metal contained in the Shang bronzes. Unfortunately, no records of speleothems at Gansu were published with data on the U, Th or Pb isotopes, making it impossible to compare these with the Cu ores. Since U is significantly more water soluble than Th, measurements of a speleothem could provide further evidence to confirm whether or not the Cu oxides derived a secondary deposit precipitated from water containing U but little Th.

The broader archaeological significance of the new type of highly radiogenic Pb in the Hexi Corridor should be further explored. Undoubtedly, it will trigger a great variety of important questions, some of which might have been discussed on the highly radiogenic Pb of the Shang bronzes, such as its rise and fall in different times and places (Jin 2008; Liu *et al*. 2015, 2018a, 2018b; Sun *et al*. 2016, 2018; Jin *et al*. 2017). Once its spatio-temporal pattern has been explicitly illustrated, it becomes more feasible for scholars to reconstruct precisely its role in the metal circulation in the Hexi Corridor, and to document the degree of mixing and cycling. In terms of provenance studies, one critical advantage of the highly radiogenic Pb recovered from the Hexi Corridor is that it is from samples of ores with a secured archaeological

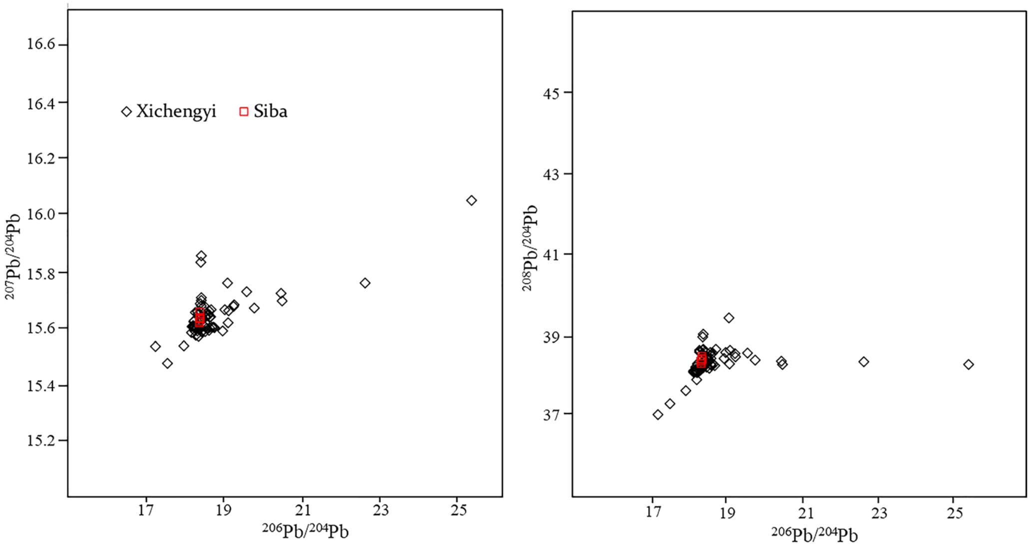

Figure 5 *Chronological patterning of Pb isotopic data in the central Hexi Corridor (Xichengyi: 4000–3700* BP*; Siba: 3700–3500* BP*). [Colour figure can be viewed at wileyonlinelibrary.com]*

context, whereas those in the Central Plains are dominated by the data from the bronze objects, with a limited number of ore samples assembled from the geological literature (thus, no archaeological context, at least no chronology). Currently, the number of Pb isotopic analyses concerning the metallurgical production (ores, slags, objects) is far from being satisfactory. Figure 5 shows the chronological pattern of the highly radiogenic Pb in the central Hexi Corridor. What can be concluded so far is that the Cu ores characterized by highly radiogenic Pb were employed in the central Hexi Corridor at least during the Xichengyi period (4000–3700 BP). It remains unclear whether it had completely disappeared in the subsequent Siba period (3700–3500 BP). The absence of highly radiogenic Pb in the samples ($n = 6$) dated to the Siba period (3700–3500 BP) has to be verified by more data in future, but if this proves to be true, it implies a significant shift in the source of Cu used in the Hexi Corridor.

So far, no evidence suggests that such a special Pb isotopic signature has been found in the early metal objects of the Central Plains, such as at Erlitou, which might imply that its source lies somewhere within the Hexi Corridor. Another set of questions that can be potentially meaningful are mixing and recycling. The Cu characterized by this newly discovered highly radiogenic Pb was certainly contemporary with Cu represented by other types of Pb isotopes (primarily common Pb) in the middle part if the Hexi Corridor. Therefore, is it possible to reverse-engineer mixing and recycling by tracking this special Pb isotopic signal? This obviously needs a significantly larger number of data on both ores and objects with a good chronology.

CONCLUSIONS

The Hexi Corridor is critical to advance our understanding of the interaction between central China and the steppe during the transition between the Late Neolithic and Early Bronze Age (*c*.4000–3500 BP). Metallurgy is undoubtedly one of the importance lenses through which archaeologists can create a more fine-grained picture. The new data demonstrate some exciting opportunities of applying Pb isotopes to capturing the metal circulation in the central Hexi Corridor. The primary supply of Cu ores derives from the local sources, with a small part that could be provenanced to much further distances. The newly discovered highly radiogenic Pb is of great interest to Chinese archaeology. It not only demonstrates a new type of highly radiogenic Pb signatures, compared with those from the Shang bronzes, used in a different time and place, but also sets up a critical benchmark for archaeologists to track down the artefacts in the Hexi Corridor and beyond. With more Pb isotopic data in future, the circulation of metal in the Hexi Corridor will make further contributions to broad archaeological narratives, especially the spread of metallurgy in the eastern extreme of Eurasia.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Data S1. Archaeological information about the sites where the ore samples were collected