JOURNAL OF QUATERNARY SCIENCE (2018) **33**(8) 934–944 ISSN 0267-8179. DOI: 10.1002/jqs.3071

JQS Journal of Quaternary Science QRA Quaternary Research Association

Early Marine Isotope Stage 3 human occupation of the Shandong Peninsula, coastal North China

FENG LI,[1,2,3]* **JIAN WANG**,[1,2] **XINYING ZHOU**,[1,2] **XIAOMIN WANG**,[1,2] **HAO LONG**,[4] **YUPENG CHEN**,[5] **JOHN W. OLSEN**[6,7] **and FUYOU CHEN**[1,2]

[1]Key Laboratory of Vertebrate Evolution and Human Origins of the Chinese Academy of Sciences, Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, Beijing, China
[2]CAS Center for Excellence in Life and Paleoenvironment, Beijing, China
[3]Department of Early Prehistory and Quaternary Ecology, University of Tübingen, Tübingen, Germany
[4]State Key Laboratory of Lake Sciences and Environment, Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, Nanjing, China
[5]Qingdao Institute for Archaeology and Cultural Relics Conservation, Qingdao, China
[6]School of Anthropology, University of Arizona, Tucson, AZ, USA
[7]Institute of Archaeology and Ethnography, Siberian Branch, Russian Academy of Sciences, Novosibirsk, Russian Federation

Received 6 April 2018; Revised 14 September 2018; Accepted 14 September 2018

ABSTRACT: Archeological studies of coastal sites have yielded a large body of information regarding the dispersal of modern humans from Africa and the coastal adaptations of various hominin groups. Coastal areas have been attractive to humans since at least the late Middle Pleistocene, according to research conducted in Africa and the circum-Mediterranean region. However, little information concerning Paleolithic occupations has come to light in coastal areas of China. Here, we report on the chronology, archeology and paleoenvironmental reconstruction of the Pleistocene Dazhushan site on the east coast of the Shandong Peninsula in North China. Evidence indicates that prehistoric humans employing a flake technology occupied the current coastal area of the peninsula by at least early Marine Isotope Stage 3 (MIS 3; *c.* 57–29 ka) when the region was an inland area dominated by a mixed broadleaved forest and grassland environment occupied by terrestrial herbivores. Based on archeological evidence brought to light along the current Chinese coastline, correlated with sea level changes that have occurred since MIS 3, we suggest that future studies of coastal migrations and adaptations in eastern China will be considerably enhanced by a deeper understanding of the geomorphological evolution of those coastal regions.
© 2018 The Authors. *Journal of Quaternary Science* Published by John Wiley & Sons Ltd

KEYWORDS: coastal; Dazhushan; Marine Isotope Stage 3 (MIS 3); Paleolithic adaptations; sea level change; Shandong.

Introduction

Demographic dispersals of *Homo sapiens* following coastal routes and their adaptations to coastal areas have been increasingly addressed in human evolution research (e.g. Stringer, 2000; Erlandson, 2001; Macaulay *et al.*, 2005; Mellars, 2006; Marean *et al.*, 2007; Fisher *et al.*, 2010; Jerardino and Marean, 2010; Parkington, 2010; Petraglia *et al.*, 2010; Erlandson and Braje, 2011; Klein and Steele, 2013; Erlandson *et al.*, 2015; Groucutt *et al.*, 2015; Will *et al.*, 2016). Coastal areas provide abundant and highly diverse marine and terrestrial resources and, as a result, have attracted human groups since at least the late Middle Pleistocene (Parkington, 2010). Many Late Pleistocene–Middle Paleolithic and Middle Stone Age sites have been found in coastal areas of Europe, West Asia and Africa (see Will *et al.*, 2016 for a recent review). Those sites have yielded a large body of information on modern human dispersals out of Africa and the coastal adaptations of various hominin groups. A coastal dispersal route for modern *H. sapiens* has been proposed based upon behavioral evidence from Middle Stone Age sites and similar finds made on the Arabian Peninsula and the Indian subcontinent (e.g. Stringer, 2000; Mellars, 2006). The profound influence of marine subsistence resources on the development of the human brain and cognitive abilities has also been suggested in nutritional terms (Parkington, 2001, 2003, 2010; Jerardino and Marean, 2010; Kyriacou *et al.*, 2014). Related topics, such as population growth and changing social structures, have been addressed as well based on research conducted at coastal archeological sites, particularly in South Africa and the circum-Mediterranean region (Klein and Steele, 2013; Marean, 2014).

In contrast, there is little substantive information regarding the Paleolithic occupation of coastal areas of China despite the fact that more than 1000 Paleolithic sites have been discovered there (Wu *et al.*, 2011). China's coastline is approximately 18 000 km long. However, stratified Paleolithic sites in areas close to modern coastlines are virtually unknown even though surface localities have been reported (You *et al.*, 1989; Fan *et al.*, 2011). The Dazhushan (DZS) site, now situated about 2 km from the Yellow Sea, has yielded a variety of archeological materials including lithic artifacts and an assemblage of faunal remains.

Here, we report on the chronology, archeology and paleoenvironmental reconstruction of the DZS site to contribute to a better understanding of the timing and adaptations of hominin groups on the east coast of China. By reviewing extant Paleolithic evidence along the coastline and sea level changes that have taken place since Marine Isotope Stage (MIS) 3, we suggest that studies of coastal migrations and adaptations in eastern China have been considerably influenced by the geomorphological evolution of those coastal regions. Enhanced research focusing on the relatively shallow

*Correspondence: Feng Li, 1Institute of Vertebrate Paleontology and Paleoanthropology, as above.
E-mail: lifeng@ivpp.ac.cn

submerged continental shelf and islands with deep shelves in eastern and southern China may in future yield more evidence relevant to the investigation of human coastal migrations and adaptations.

Materials and methods

The DSZ site (35°47′22.4″N, 120°00′42.4″E; 58 m asl) is located in the eastern foothills of the eponymous mountain range in Qingdao City, Shandong Province (Fig. 1). The site was discovered in 1980 and Pleistocene animal fossils were collected (You *et al.*, 1989). In 2012, a joint team from the Institute of Vertebrate Paleontology and Paleoanthropology (IVPP) of the Chinese Academy of Sciences (CAS), and the Qingdao Institute for Archaeology and Cultural Relics Conservation re-investigated the locality and discovered stone artifacts on the surface. The site was subsequently explored in 2013 by opening a 30-m^2 trench reaching a total depth of about 5.5 m. To establish and control provenance, each stratigraphic layer yielding archeological material was dug in 10-cm spits. Lithic artifacts larger than 2 cm and identifiable mammalian fossils were piece-plotted with a total station. Due to the time constrains imposed by the rescue nature of the DZS excavation, systematic sieving of sediment samples was not undertaken during the 2013 excavation. Four stratigraphic units were identified, consisting mainly of fluvial and peat deposits with a total thickness of 5.5 m (Fig. 2): Unit 1 is a yellowish clay with granite breccia, 0–2.0 m; Unit 2 consists of yellowish sand with undulating bedding containing a small number of bones and artifacts, 2.0–3.0 m; Unit 3 is a peat deposit including abundant wood fragments, stone tools and faunal remains, 3.0–4.5 m. Unit 3 lies unconformably on an underlying sterile deposit; Unit 4 consists of black sand and gravel with bedding layers, 4.5–5.5 m. Units 2 and 4 underwent relatively intense hydraulic processes, indicated by coarse sandy deposits and observable bedding structures (Supporting Information, Fig. S1). A stratigraphic unconformity between Units 3 and 4 is marked by a red dashed line in Fig. 2a, indicating a sedimentary discontinuity and erosion. Between Units 2 and 3, the deposit had been reworked in the western part of Unit 3 resulting in an uneven horizontal boundary between Units 2 and 3. Based on an analysis of their spatial distribution, most of the Unit 2 artifacts came from the western part of this unit which had experienced some redeposition from Unit 3 (Fig. 3). Therefore, the small number of archeological remains present in Unit 2 may have been eroded from the underlying Unit 3. Considering the small sample of artifacts recovered from Unit 2 and their secondary context, we discuss the finds from Units 2 and 3 cumulatively below.

Dating

Seven organic samples from the archeological units were selected for accelerator mass spectrometry (AMS) radiocarbon dating; the samples were processed in the AMS Centre of the School of Physics at Peking University (BA) and by Beta Analytic, Inc. (Beta). The dating method used in the AMS laboratory at Peking University (PKU) has been described in detail (Wu *et al.*, 2012), and Beta Analytic's

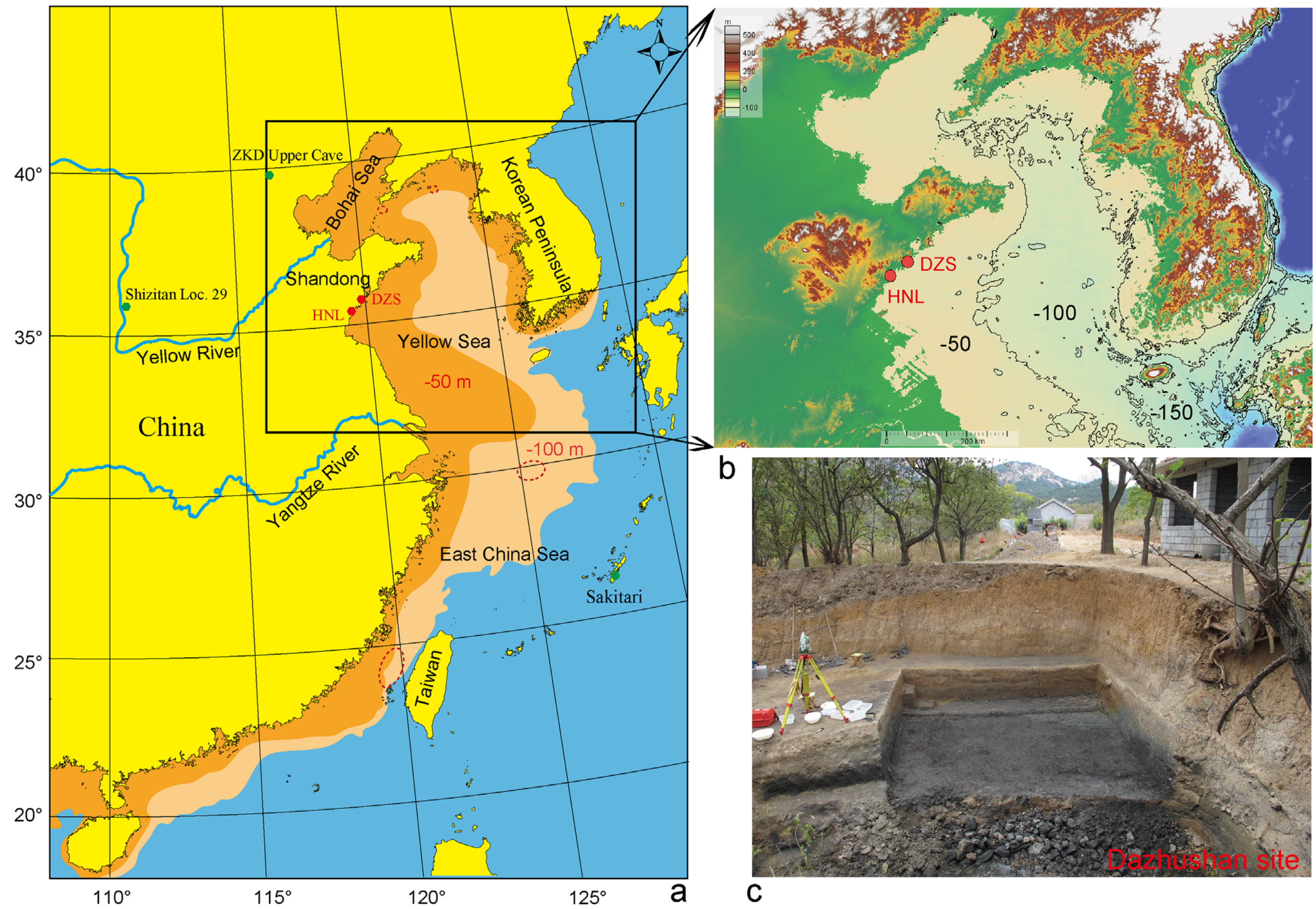

Figure 1. Location of the Dazhushan site and the geomorphology of the east coast of China. (a) Location of sites mentioned in the text, and coastal area reflecting sea levels 50 and 100 m lower than at present; the red dashed line indicates where faunal remains have been recovered underwater. (b) Map showing the contour of the Bohai and northern Yellow Seas at 50-m intervals created using GeoMapApp software (www.geomapapp.org/). (c) Excavation pit and landscape at the Dazhushan site (taken from the east).

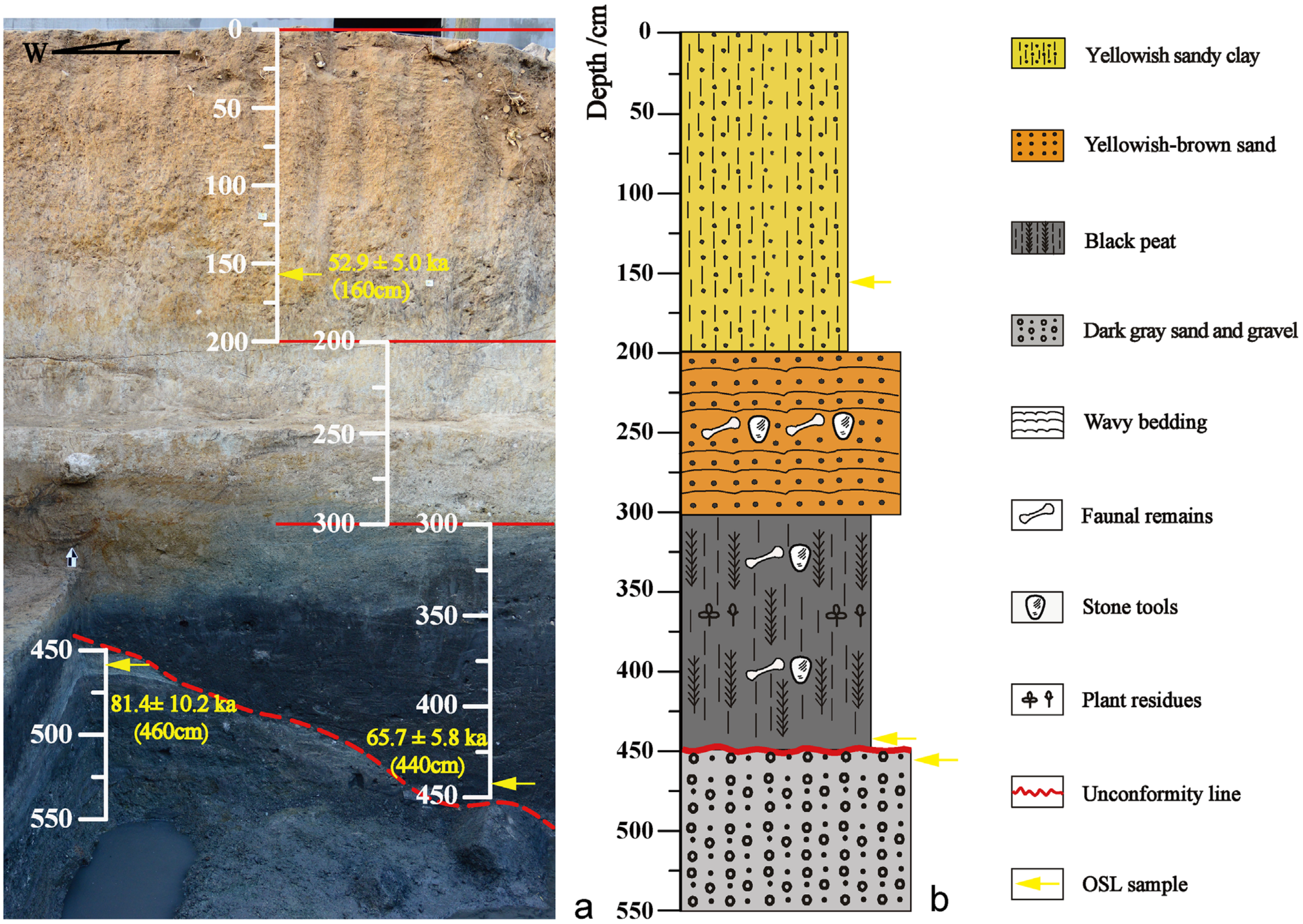

Figure 2. Site stratigraphy and sample location. (a) North section of excavation pit showing locations of OSL and pollen samples. (b) Stratigraphic column (modified after Wang *et al.*, 2018).

radiocarbon measurement procedures are described on their website (https://www.radiocarbon.com/pretreatment-carbon-dating.htm). Three optically stimulated luminescence (OSL) samples from Units 1, 3 and 4 were analyzed in the Luminescence Dating Laboratory of the Nanjing Institute of Geography and Limnology Chinese Academy of Sciences (NIGLAS). Sample preparation for OSL dating followed the method described by Long *et al.* (2015); we used the single-aliquot regenerative-dose (SAR) protocol (Murray and Wintle, 2003) for equivalent dose measurement, and the dose rate was determined by neutron activation analysis (NAA) to quantify the concentrations of uranium (U), thorium (Th) and potassium (K).

Palynological analysis

Sediment samples were collected from Units 2–4 for paleoclimate and vegetation reconstruction of the site's vicinity. A total of 20 samples were obtained at 20-cm intervals from 150 cm below the current ground surface to the bottom of the north section. We obtained sediment samples from the north section of the excavation trench and the depth of the samples

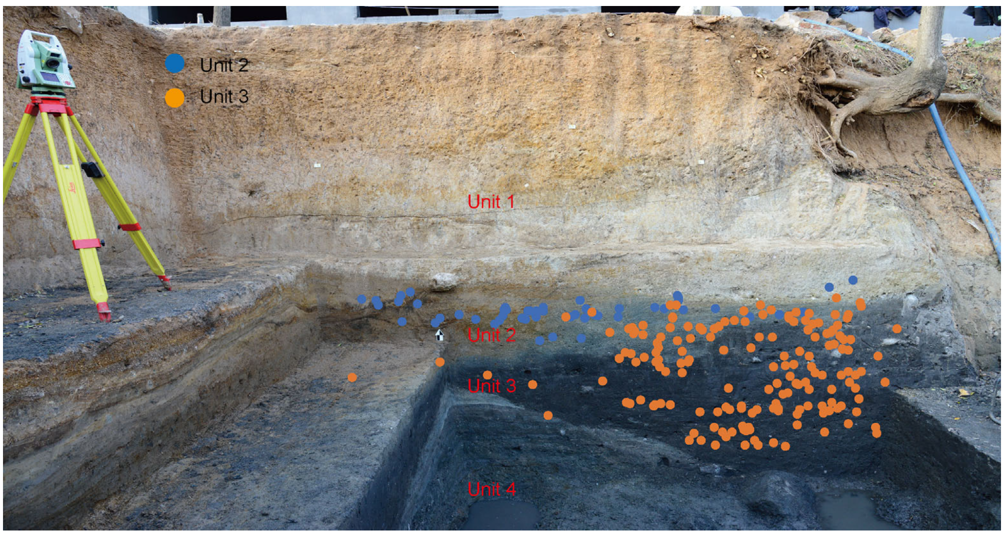

Figure 3. Vertical distribution of stone artifacts at the Dazhushan site.

Table 1. AMS dating results by depth and stratigraphic layer at the Dazhushan site.

Lab. code	Depth (cm)	Unit	Material	$\delta^{13}C$ (‰)	^{14}C age (a BP)	Calibrated age (cal a BP, 2σ)
BA132048	270	3 (AL)	Bone	n/a	42 230 ± 370	46 259–44 864
BA132049	276	2 (AL)	Bone	n/a	Failed due to low yield	
BA132050	344	3 (AL)	Wood	n/a	44 160 ± 510	48 766–46 235
Beta-393205	344	3 (AL)	Wood	−26.0	>43 500	
Beta-393207	344	3 (AL)	Bone	−18.2	>43 500	
BA132051	374	3 (AL)	Bone	n/a	>45 000	
Beta-393206	374	3 (AL)	Wood	−27.4	>43 500	

AL, archeological layer.

was calculated cumulatively from the surface (Fig. 2). Sediment samples weighing approximately 150 g each were processed by using standard palynological procedures using sieving and heavy liquid extraction (Moore and Webb, 1978; Li and Du, 1999) in the Key Laboratory of Vertebrate Evolution and Human Origins, IVPP, CAS. The number of pollen grains yielded by each sample was counted on 2–3 slides, and more than 200 pollen grains were identified with optical microscopy at a magnification of 400×. Pollen percentages were calculated for each taxon with regard to the total sum of pollen recovered, and a percentage diagram was constructed using TILIA software (Grimm, 1990).

Lithic and faunal analyses

During the 2013 excavations at DZS, more than 500 stone objects were piece-plotted with a total station. The sedimentary matrix and large number of heavily weathered pieces suggest the assemblages underwent secondary redeposition. Therefore, we applied very strict criteria in identifying lithic artifacts: only flakes bearing clear percussion features such as a point of percussion, bulb, and/or clear negative scars on the dorsal face, cores with larger and multiple negative scars (>1.5 cm) and continuously retouched blanks are included in this study. A total of 238 stone artifacts were analyzed using a techno-typological approach. Because we did not include a complete assemblage in our analysis—note the significant lack of chunks and debris—the results presented here are more the outcome of qualitative rather than strictly quantitative analyses.

Approximately 850 animal bone fragments were piece-plotted with a total station during the 2013 excavation, but the number of faunal remains studied is slightly larger because some specimens were collected without being piece-plotted. Here, we simply describe the taxa represented by the faunal assemblage of morphologically identifiable specimens. Detailed analyses of the taphonomy and exploitation of mammalian resources at DZS will be reported in a separate publication.

Results

Age constraints

Nine chronometric dates have been obtained from the DZS site, among which seven are associated with layers bearing archeological materials. One bone sample from Unit 2 yielded insufficient organic material for dating. Dates on bones from Unit 3 span a range from > 45 000 (infinite) to 42 230 ± 370 ^{14}C a BP, and three wood samples from Unit 3 all yielded infinite AMS determinations, specifically >43 500 ^{14}C a BP (Table 1). The OSL determinations from Units 4 (81.4 ka), 3 (65.7 ka) and 1 (52.9 ka) are consistent within the sequence, showing increasing age with depth (Table 2; Wang *et al.*, 2018). Considering the secondary context of the archeological materials, the age of the human occupation at DZS could be earlier than that of Unit 3, from which most of the stone artifacts were recovered. The OSL age of Unit 4 can certainly be considered the *terminus post quem* for the human occupations of DZS. The AMS dates are close to the determinative limits of the radiocarbon method and most of them are infinite. Therefore, the OSL ages can be considered the best representation of the age of the DZS site. The OSL dates from the bottom of Units 3 and 1 probably bracket the human occupation span of the site to a period of roughly 65.7–52.9 ka because most of the archeological finds were concentrated in the upper part of Unit 3.

The site and regional vegetation

Pollen grains recovered between the 150- and 370-cm levels of the sampled section are not included in the accompanying palynological diagrams due to low pollen concentrations in the sediments. However, we extracted abundant pollen remains below 370 cm, which also contains the principal archeological layer, yielding abundant artifacts and vertebrate fossils. A total of 28 pollen taxa were identified from 10 samples, including 10 arboreal taxa and 15 herbaceous taxa (Wang *et al.*, 2018; *Appendix* S1). The pollen percentage diagrams and total pollen concentration by depth are presented in Fig. 4. The pollen spectra are dominated by *Artemisia* (herbaceous plants and shrubs often grouped in English as mugwort, wormwood or sagebrush) and members of the goosefoot family, Chenopodiaceae, which comprise more than 81% of the total pollen recovered. Based on constrained cluster analysis (CONISS) of pollen percentages and on stratigraphy, the pollen record from the segment 370–550 cm is subdivided into four discrete pollen zones (Fig. 4).

Table 2. OSL dating results by depth and stratigraphic layer at the Dazhushan site.

Lab. no.	Depth (cm)	Unit	Material	Water (%)	U (ppm)	Th (ppm)	K (%)	D_e (Gy)	Age (ka)	Reference
NL-874	160	1	Sediment	7 ± 5	2.87 ± 0.11	10.7 ± 0.3	2.48 ± 0.07	223.5 ± 2.8	52.9 ± 5	Wang *et al.* (2018)
NL-875	440	3 (AL)	Sediment	15 ± 5	2.16 ± 0.09	6.63 ± 0.21	3.01 ± 0.08	241.9 ± 8	65.7 ± 5.8	Wang *et al.* (2018)
NL-876	460	4	Sediment	13 ± 5	12.4±0.29	12 ± 0.34	2.42 ± 0.07	527.6 ± 17.8	81.4 ± 10.2	Wang *et al.* (2018)

AL, archeological layer.

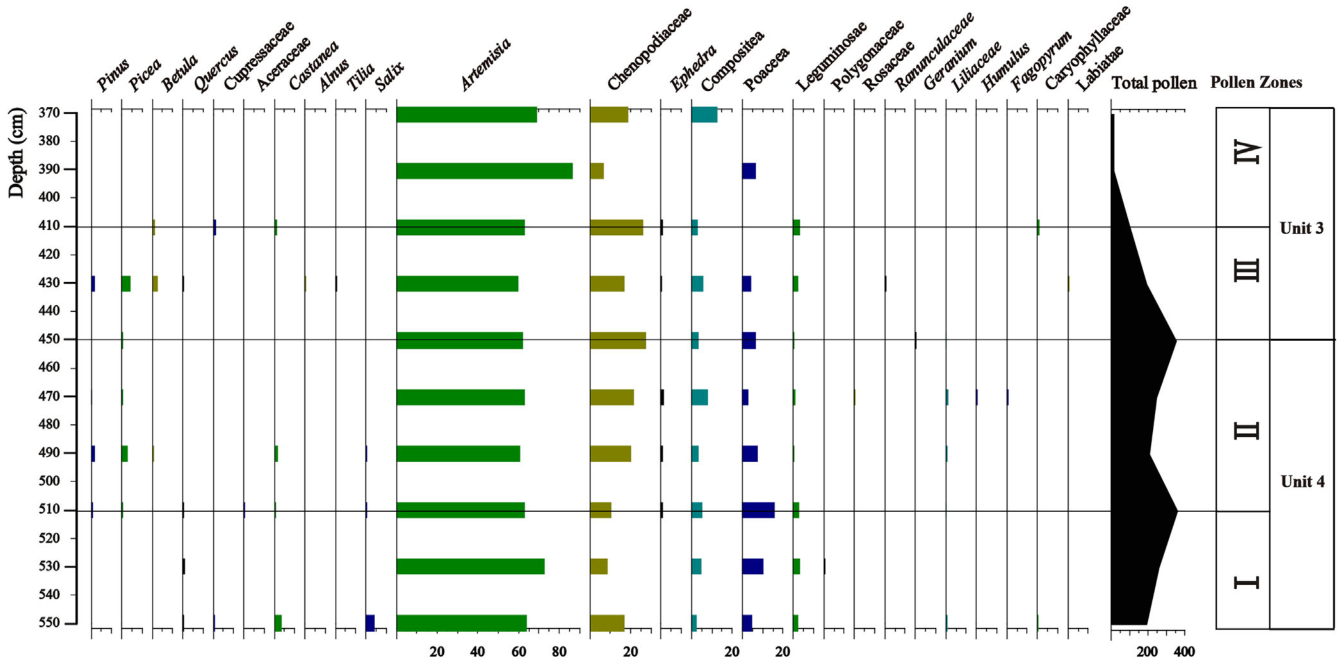

Figure 4. Percentage diagrams and total pollen concentrations at the Dazhushan site (modified after Wang *et al.*, 2018).

Zone I (550–510 cm, lower Unit 4)

This zone features a high pollen concentration and the total number of pollen grains increases gradually. Here, pollen assemblages were dominated by species of *Artemisia* and chenopods (mean 76%), with a considerable proportion of other herbaceous taxa such as members of the families Poaceae, Compositae and Leguminosae. There are some temperate deciduous trees present such as *Castanea* (chestnut) and *Salix* (willow), and the presence of some spores, including those of ferns of the family Polypodiaceae, indicate an open grassland vegetation community with sparse deciduous forest cover, and a relatively warm and humid climate.

Zone II (510–450 cm, upper Unit 4):

This zone is characterized by the highest pollen concentration of the entire section. Members of the Chenopodiaceae represent a higher proportion while *Artemisia* and Chenopodiaceae still dominate the pollen spectrum. Other herbaceous components include members of the Poaceae family of grasses and Liliaceae (lilies), *Ephedra* (mahuang) and *Humulus* (hop). This zone features a relatively high proportion of both coniferous and deciduous trees including *Pinus* (pine), *Picea* (spruce), *Betula* (birch) and *Quercus* (oak). The increase in coniferous trees probably indicates that temperatures decreased during this period.

Zone III (450–410 cm, lower Unit 3)

The spectrum here exhibits a gradual decline in pollen concentration; nonetheless, this zone is also dominated by *Artemisia* and members of the family Chenopodiaceae, and the percentage of Chenopods continues to increase to more than 20% of the assemblage. In addition to the Poaceae, other pollen values are low including *Ephedra* and members of the families Leguminosae, Liliaceae and Labiatae. Furthermore, this zone contains a relatively high amount of various arboreal pollen such as *Betula*, *Pinus*, *Quercus*, and *Picea*, and the presence of *Alnus* (alder) and *Tilia* (linden), which are suited to warm and humid climates, reveal a shrub grassland and mixed coniferous–deciduous forest, probably under relatively warm and wet climatic conditions.

Zone IV (410–370 cm, middle Unit 3)

This zone is marked by a substantial reduction in pollen concentrations. It reflects a decrease in arboreal pollen and few deciduous trees are present, including *Betula* and *Quercus*. Moreover, *Artemisia* and members of the Chenopodiaceae assume the highest proportions in the pollen spectra. Other herbs such as *Ephedra* and species of the families Compositae, Poaceae and Caryophyllaceae appear in the early part of the record, but later a low amount of *Ephedra* pollen indicates a temperate grassland vegetation community.

Here, we briefly describe the palynological results from the 150–370 cm segment of the stratigraphic column. The pollen concentration here is very low, mostly consisting of *Artemisia* and members of the Chenopodiaceae, with few representatives of *Quercus*, *Ephedra*, and the families Leguminosae and Poaceae. These results indicate a progressively colder climate.

The DZS faunal assemblage is dominated by larger terrestrial mammals. Fourteen mammalian taxa have been identified from the site, including two small carnivores, one proboscidean, four large perissodactyls and seven artiodactyls (Table 3). There are also four bird limb bone fragments and several eggshells present in the assemblage, but species-level identification of those remains has yet to be accomplished. The most abundant species in the assemblage are wet-land/woodland dwellers such as *Sus scrofa* (boar), *Cervus nippon* (sika deer) and *Dicerorhinus mercki* (*Stephanorhinus kirchbergensis*; Merck's rhinoceros), consistent with the relatively warm and moist environment suggested by the pollen data of lower Unit 3. Grasslands were also present as indicated by the presence of *Equus caballus* (horse) and *Equus hemionus* (onager).

More detailed taphonomic analyses are required to differentiate the anthropogenic faunal assemblage from natural accumulations at the DZS site. However, it is worth mentioning here that most of the faunal remains could represent prey animals that were consumed by humans. There are no signs

Table 3. Numbers of identifiable specimens (NISP) in the faunal assemblages of the Dazhushan site.

Class	Genus and species	Common name	NISP (% NISP)
Carnivora	*Viverra* sp. indet.	Civet cat	2 (0.4)
	Pachycrocuta sp. indet.	Hyena	1 (0.2)
Proboscidea	Elephantinae gen. et sp. indet.	Elephant	5 (1.03)
Perissodactyla	*Coelodonta antiquitatis*	Woolly rhinoceros	7 (1.45)
	Dicerorhinus mercki	Merck's rhinoceros	44 (9.12)
	Equus caballus	Horse	18 (3.74)
	Equus hemionus	Onager	80 (16.56)
	Equus sp. indet.	Equine	73 (15.12)
Artiodactyla	*Sus scrofa*	Boar	36 (7.45)
	Cervus elaphus	Red deer	31 (6.42)
	Cervus (*Sika*) *nippon*	Sika deer	85 (17.61)
	Capreolus manchuricus	Roe deer	8 (1.66)
	Procapra przewalskii	Przewalski's gazelle	50 (10.35)
	Spirocerus sp. indet.	Topis	1 (0.2)
	Bos primigenius	Aurochs	36 (7.45)
	Bos sp. indet.	Cattle	6 (1.24)

of small mammals, such as rodents, in the assemblage and carnivores are quite rare; only three fragmentary teeth of a viverrid and a hyena were found. The dominance of larger terrestrial mammals, and the limited presence of rodents and carnivores, suggests that anthropogenic factors may have been primarily responsible for the accumulation of animal remains at the site.

Lithic assemblage

Table 4 summarizes the basic technological characteristics of the DZS lithic assemblage, among which 39.9% preserve cortex indicating a gravel origin and 5.9% retain nodule cortex indicating an outcrop origin. Most of the DZS artifacts are manufactured from various volcanic rocks dominated by basalt, and quartzite obtained as poorly rounded pebbles from nearby river beds, based upon the remaining cortex. A small number of artifacts were produced from low-quality quartz and relatively high-quality quartz crystal, probably obtained from nearby outcrops.

A diverse range of nuclei make up 11% of the assemblage as a whole (Fig. 5: 1–3). Several cores can be classified as discoidal, but most are atypical exhibiting multidirectional removal from only one face. Boat-shaped single platform cores bearing removals from two broad faces and one narrow face were also found (Fig. 5: 1). The remaining assemblage of nuclei includes tested pieces, core-choppers and polyhedrons that do not bear signs of strategic organization of their platforms or flaking surfaces. Although the DZS cores demonstrate various reduction sequences, the products are all generally flakes indicating no signs of strategic pre-determination of their morphology. The average size of complete nuclei ($n=25$) is relatively small with mean lengths, widths and thicknesses of 53.3, 49.5 and 37.7 mm, respectively. The series of complete flakes also shows poor-organized characteristics (Fig. 5: 4–6): platforms are usually plain or cortical

Table 4. Techno-typological composition of the lithic industry from the Dazhushan site.

Class	Type	Number
Nuclei ($n=27$)	Tested pieces	6
	Single platform core	6
	Double platform and polyhedral core	7
	Core-chopper	3
	Discoidal core	5
Blanks ($n=182$)	Core tablet	2
	Débordant	2
	Whole flake with cortical platform	16
	Whole flake with plain platform	91
	Whole flake with facetted platform	4
	Whole flake with dihedral platform	2
	Whole flake with crushed platform	20
	Flake fragment	44
	Chunk	1
Retouched pieces ($n=29$)	Single-edged side-scraper	13
	Double-edged side-scraper	1
	Convergent scraper	1
	Transverse scraper	5
	Denticulate	7
	Notched piece	1
	Point	1
Total		238

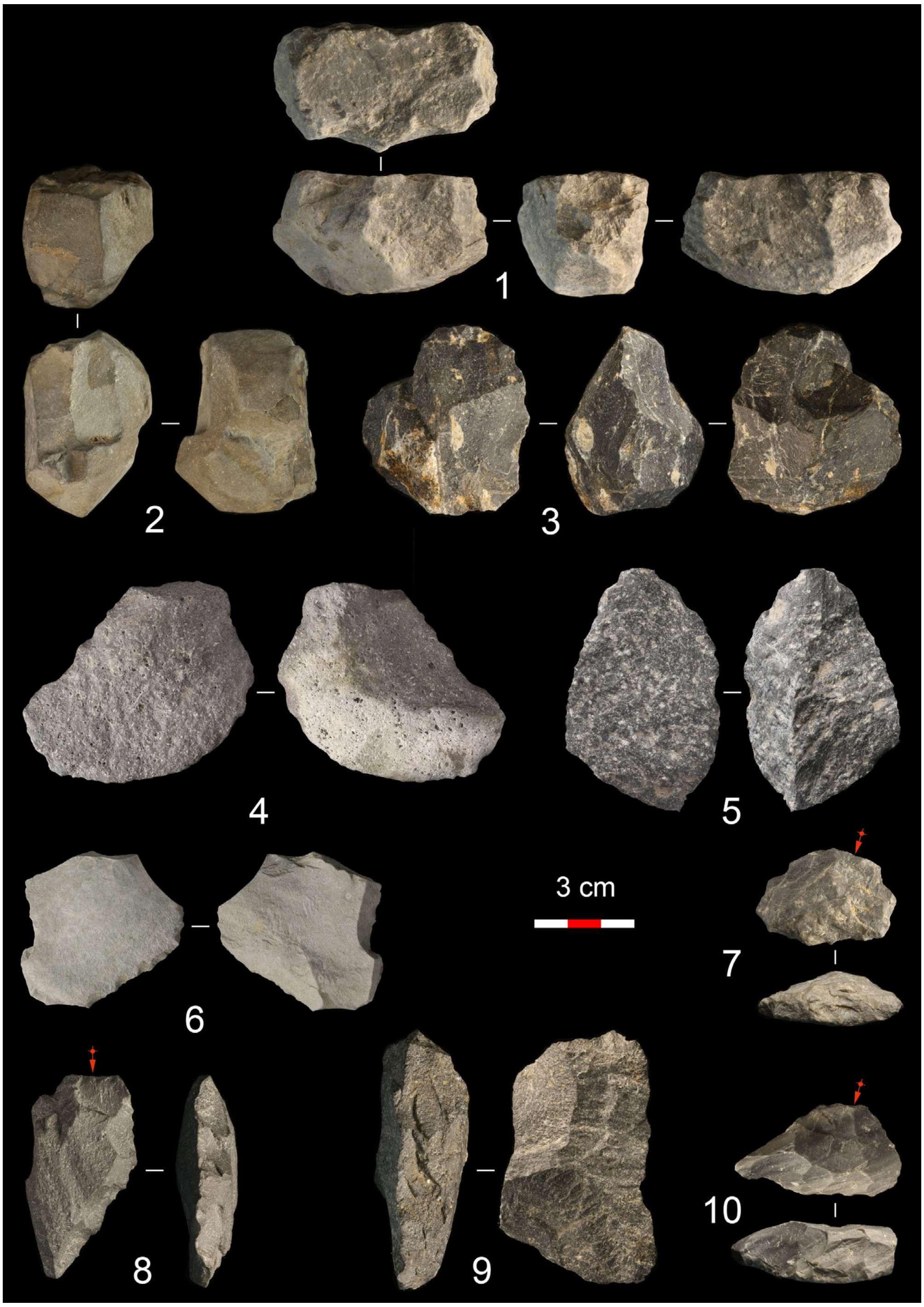

Figure 5. Selected stone artifacts from the Dazhushan site. (1) Boat-shaped flake core, (2) polyhedral core, (3) discoidal core, (4–6) flakes, (7, 10) transverse scrapers, (8, 9) side-scrapers.

(107 of 137 specimens), and only a few facetted platforms are present (four of 137); the identified dorsal scar orientations exhibit diverse patterns but are predominantly unidirectional from the proximal end (59 out of 110), and parallel (three out of 110) or centripetal (one out of 110) dorsal scar patterns are rare; the blanks are clearly flake-based ($mean_{length/width} = 1.0$, $SD_{length/width} = 0.3$). The average size of complete flakes ($n = 137$) is small with mean lengths, widths and thicknesses of 37.6, 37.3 and 14.4 mm, respectively. Overall, core reduction strategies show features of simple flake manufacture without significant attention to the morphology of the products.

All retouched pieces from the DZS site are flake-based. Denticulates and various scrapers, such as side-scrapers, transverse scrapers and convergent scrapers, are the dominant types (Fig. 5: 7–10). Most scrapers were retouched abruptly or semi-abruptly with mean edge angles of 70° ($n = 20$, SD = 18°). With respect to overall typology, the DZS retouched tool assemblage bears much closer affinity to the Early Paleolithic (Gao, 1999; Gao and Norton, 2002) than to the Late Paleolithic of China.

Discussion

The archeological finds from the DZS site bear important implications for our understanding of Pleistocene human evolution and adaptations in coastal China. Although several surface collections of archaic-looking chipped stone tools have been previously reported in Fujian and Shandong Provinces (e.g. You *et al*., 1989; Fan *et al*., 2011), few reliably dated Late Pleistocene sites in coastal areas have been found. The DZS site is one of just a few exceptions. Another similar locality situated near the modern coastline in the same area is the Huangniliang (HNL) site, about 50 km south of DZS (Chen *et al.*, 2015; Nian *et al.*, 2015). The HNL site, dating to 59–54 ka (OSL), is currently situated approximately 4.2 km from the Yellow Sea. These sites, the only two dated Paleolithic localities within 5 km of mainland China's modern coastline (Fig. 1a), were both buried in low hills on the Shandong Peninsula. Although this does not necessarily imply that activities of ancient hominins in the region were limited to the hilly lowlands, outcrops of quartz and various volcanic rocks near those hills may have initially attracted Paleolithic knappers to the DZS and HNL sites. The lithic technology preserved in these two sites shows many similarities; both have yielded a flake-based technocomplex with an inventory dominated by scraper–denticulate tools. It appears that this area was probably occupied by groups sharing a similar lithic technology, at least during early MIS 3. The subsistence strategies of these hominin groups cannot be reconstructed based on the discoveries at the HNL site due to the absence of preserved bone and the lack of a pollen record currently available there. At DZS, evidence from both the pollen and the faunal records demonstrates that hominin groups there lived in a mixed broadleaved forest and grassland environment also occupied by terrestrial herbivorous mammals. Although hunting ability is difficult to assess due to the secondary context of the faunal remains, no evidence of marine resource exploitation has been observed in either the archeological or paleoenvironmental records.

Marine resources not only provide food for hominins but also raw materials for fabricating ornaments and containers. Although some scholars have proposed that only modern *H. sapiens* is capable of exploiting marine resources systematically (Marean, 2014), in fact, coastal adaptations were successfully achieved by both Neandertal and contemporary African hominin groups (e.g. Stiner, 1994; Finlayson, 2008; Stringer *et al.*, 2008; Will *et al.*, 2016). The ability of modern humans to cross broad expanses of open sea among the islands of southern Asia and Australia has been suggested by evidence of occupations there as early as *c.* 65 ka (Mijares *et al.*, 2010; Clarkson *et al.*, 2017). However, material cultural evidence for the exploitation of marine resources appeared in Southeast Asia only around 42 ka and is commonly placed in the modern human behavioral package in this region (O'Connor *et al.*, 2011; Langley *et al.*, 2016). Although modern humans were well established in inland South China during MIS 5 (Liu *et al.*, 2010, 2015; Bae *et al.*, 2014; but see Michel *et al.*, 2016), the makers of the DZS and HNL lithic assemblages during early MIS 3 remain unknown. If modern humans are indeed exclusively responsible for the exploitation of marine resources in East Asia, the absence of such exploitation at DZS might be an indication that modern humans had not arrived in this area by early MIS 3.

However, an alternative, more reasonable, explanation considers sea level changes and the geomorphological evolution of the Chinese east coast during the Late Pleistocene. The northern part of the coastal shelf of China has formed since MIS 6, probably because of tectonic subsidence (Li, 1991; Sun *et al.*, 2003). The Yellow Sea and East China Sea are relatively shallow; the continental shelf there generally has a bathymetric depth of <100 m (Fig. 1a). Based on the reconstruction of global sea levels and that of the western Pacific Ocean (Wang and Wang, 1980; Wang *et al.*, 1981; Waelbroeck *et al.*, 2002; Siddall *et al.*, 2003; Lambeck *et al.*, 2014; Rohling *et al.*, 2014; Shi *et al.*, 2016), sea levels were generally 50–80 m lower than at present during early MIS 3 in the Yellow Sea and East China Sea. This would have dramatically altered the configuration of the coastline; consequently, the DZS and HNL sites were at least 150–200 km from the early MIS 3 coastline (Figs 1a and S2). The lower sea level rendered the current coastal area of the Shandong Peninsula an inland region, which fits the paleoenvironmental reconstruction for DZS based upon the pollen and faunal records. Deep-sea pollen records in the western Pacific also demonstrate that the continental shelves of eastern and southern China were covered by herb-dominated grasslands that included taxa such as *Artemisia*, Poaceae and Cyperaceae during MIS 3 (Sun *et al.*, 2000, 2003).

The shallow continental shelf of the Yellow and East China Seas may have profoundly influenced subsequent Paleolithic coastal adaptations in China after the widespread establishment of modern humans in Northern China around 40 ka (Shang *et al.*, 2007; Li *et al.*, 2018). Evidence of marine resource exploitation is present on Okinawa, in Japan, around 35 ka (Sakitari Cave; Fujita *et al.*, 2016). There are only a limited number of middle MIS 3 to the early Holocene sites in current coastal areas of mainland China, with evidence of marine resource exploitation coming from the Upper Cave at Zhoukoudian (ZKD UC) in Beijing (Pei, 1939) where three perforated *Arca* (ark clam) bivalve shells were found; the revised age of the cave is at least 34 ka (Li *et al.*, 2018), at which time the coast was approximately 500 km distant. Another inland site on the Loess Plateau, Shizitan Locality 29 dating to the Last Glacial Maximum (LGM), has yielded a few marine bivalve shell ornaments including examples made from *Scapharca kagoshiensis* and members of the family Veneridae (Song and Shi, 2013). The approximate distance of this site to the LGM coastline is 1500 km, and thus these finds imply that long-distance exchange or foraging trips to acquire marine resources were possible in the later Late Pleistocene of China.

Many shell middens dating to the Middle Holocene (*c.* 7–6 ka) have been found in coastal areas of Guangxi, Guangdong, Fujian, Shandong and Liaoning Provinces (Yuan, 1995; Yuan *et al.*, 2002); this is the period when elevated sea levels essentially created modern coastlines. This increase in marine resource exploitation in eastern China corresponds with coastline changes from the later Late Pleistocene to the Middle Holocene. From early MIS 3 to the early Holocene, sea levels are estimated to have been at least 50 to 100 m lower than their current positions (Wang and Wang, 1980; Wang *et al.*, 1981; Siddall *et al.*, 2003; Lambeck *et al.*, 2014; Rohling *et al.*, 2014; Shi *et al.*, 2016) which exposed a large area of continental shelf east of the current coastline (Fig. S2). This suggests that many potential archeological sites falling within the period from MIS 3 to the middle Holocene (roughly 59–7 ka) have been submerged due to marine transgressions. Considering the landscapes exposed between the current coastline and that of the later Late Pleistocene, we should expect to find less evidence of coastal adaptations before the middle Holocene in mainland China. Research on Holocene human occupations also suggests that the spatial and temporal distribution of Neolithic sites was fundamentally controlled by landscape evolution (particularly changes in coastlines), which were ultimately governed by eustatic changes (Wang *et al.*, 2012; Wu *et al.*, 2014; Zheng *et al.*, 2018). Consequently, research on Paleolithic costal adaptations in East Asia relies more on areas with deeper continental shelves, as also been proposed by others (e.g. Erlandson and Braje, 2011). For decades, the potential of finding Paleolithic archeological materials on continental shelves has been a topic of speculation (Emery and Edwards, 1966), and recent underwater archeology has recovered evidence of coastal adaptations in many places, particularly in the circum-

Mediterranean and Arabian regions (e.g. Bailey and Flemming, 2008; Bailey *et al.*, 2015, 2017; Benjamin et al., 2017; Flemming, 2017). For some time, it has been reported that human and other mammalian fossils are occasionally found in the nets of fisherfolk operating in the Bohai Sea, the Yellow Sea, the East China Sea and the Taiwan Strait (Sun *et al.*, 1992; You *et al.*, 1995; Liu and Fu, 1997; Qi and Ho, 1999; Cai, 2001; Chang *et al.*, 2015). Some of these fossils have been dated to late MIS 3 and the LGM and bear traces of human modification (Hu, 2004; Peng and Fan, 2008). Therefore, understanding coastal adaptations in East Asia would be enhanced by focusing on the shallow continental shelf, although admittedly this will not be easy.

Conclusions

Recent archeological discoveries on the Shandong Peninsula indicate that hominins using a flake-based technocomplex occupied the current coastal area of the peninsula by at least early MIS 3. The lower sea levels of early MIS 3 extended the current coastal area around 150–200 km to the east, and thus the DZS site area was an inland region during its occupation. The pollen and faunal assemblages from DZS indicate that the site's occupants lived in a mainly mixed forest and grassland environment alongside terrestrial herbivorous mammals. Since early MIS 3, rising sea levels have submerged a large area along the eastern coast of China, so less evidence of coastal occupations would be expected in current coastal areas. As a consequence, future studies of Paleolithic coastal adaptations in East Asia will rely more on areas adjacent to much deeper continental shelves where the potential for discovering sites close to Pleistocene paleo-coastlines is greater.

Acknowledgements. We thank Yuhai Lin, Director of the Qingdao Institute for Archeology and Cultural Relics Conservation, Jianhong Wong, Director of the Huangdao Museum and their archeology crew for making the Dazhushan excavations progress smoothly and productively. We appreciate the thoughtful comments of Dr Manuel Will and one anonymous reviewer. Any errors are solely our responsibility. F. Li thanks the Alexander Von Humboldt Foundation for a postdoctoral stipend and the Youth Innovation Promotion Association, CAS (grant No. 2017102), H. Long thanks the Youth Innovation Promotion Association CAS (grant No. 2015251), and J. Olsen thanks the Chinese Academy of Sciences for a President's International Fellowship iInitiative Grant (No. 2018VCA0016) which greatly facilitated this study. This research was supported by the National Natural Science Foundation of China (grant No. 41502022).

Supporting information

Figure S1. Sections showing the bedding structures of sediments at the Dazhushan site (inside scale is 10 cm).
Figure S2. Sea level changes during the Late Pleistocene (a) and reconstruction of environments on the coast of the Shandong Peninsula during early MIS 3 (b).
***Appendix* S1.** Palynological results from the Dazhushan site.

Abbreviations. AMS, accelerator mass spectrometry; CAS, Chinese Academy of Sciences; DZS, Dazhushan; IVPP, Institute of Vertebrate Paleontology and Paleoanthropology; LGM, Last Glacial Maximum; MIS, Marine Isotope Stage; OSL, optically stimulated luminescence.

References

Bae CJ, Wang W, Zhao J *et al.* 2014. Modern human teeth from Late Pleistocene Luna cave (Guangxi, China). *Quaternary International* **354**: 169–183.

Bailey GN, Devès MH, Inglis RH *et al.* 2015. Blue Arabia: palaeolithic and underwater survey in SW Saudi Arabia and the role of coasts in Pleistocene dispersals. *Quaternary International* **382**: 42–57.

Bailey GN, Flemming NC. 2008. Archaeology of the continental shelf: marine resources, submerged landscapes and underwater archaeology. *Quaternary Science Reviews* **27**: 2153–2165.

Bailey GN, Sakellariou D, Alsharekh A *et al.* 2017. Africa-Arabia connections and geoarchaeological exploration in the southern Red Sea: preliminary results and wider significance. In *Under the Sea: Archaeology and Palaeolandscapes of the Continental Shelf.* Coastal Research Library 20, Bailey GN et al. (eds). Dordrecht: Springer; 361–373.

Benjamin J, Rovere A, Fontana A *et al.* 2017. Late Quaternary sea-level changes and early human societies in the central and eastern Mediterranean Basin: an interdisciplinary review. *Quaternary International* **449**: 29–57.

Cai B-q. 2001. Fossil human humerus of Late Pleistocene from the Taiwan Straits. *Acta Anthropologica Sinica* **20**: 178–185 [in Chinese with English abstract].

Chang CH, Kaifu Y, Takai M *et al.* 2015. The first archaic *Homo* from Taiwan. *Nature Communications* **6**: 6037.

Chen F-y, Li G, Li Y *et al.* 2015. A preliminary report of the Huangnilianng Paleolithic site, Shandong Province. *Acta Anthropologica Sinica* **34**: 21–27 [in Chinese with English abstract].

Clarkson C, Jacobs Z, Marwick B *et al.* 2017. Human occupation of northern Australia by 65,000 years ago. *Nature* **547**: 306–310.

Emery KO, Edwards RL. 1966. Archaeological potential of the Atlantic Continental Shelf. *American Antiquity* **31**: 733–737.

Erlandson JM. 2001. The archaeology of aquatic adaptations: paradigms for a new millennium. *Journal of Archaeological Research* **9**: 287–350.

Erlandson JM, Braje TJ. 2011. From Asia to the Americas by boat? Paleogeography, paleoecology, and stemmed points of the northwest Pacific. *Quaternary International* **239**: 28–37.

Erlandson JM, Braje TJ, Gill KM *et al.* 2015. Ecology of the kelp highway: did marine resources facilitate human dispersal from Northeast Asia to the Americas? *The Journal of Island and Coastal Archaeology* **10**: 392–411.

Fan X-c, Wu J-p, Huang Y-m *et al.* 2011. A Late Paleolithic site discovered at Shenhu Bay, Jinjiang City, Fujian Province. *Acta Anthropologica Sinica* **30**: 299–236 [in Chinese with English abstract].

Finlayson C. 2008. On the importance of coastal areas in the survival of Neanderthal populations during the Late Pleistocene. *Quaternary Science Reviews* **27**: 2246–2252.

Fisher EC, Bar-Matthews M, Jerardino A *et al.* 2010. Middle and Late Pleistocene paleoscape modeling along the southern coast of South Africa. *Quaternary Science Reviews* **29**: 1382–1398.

Flemming NC. 2017. The role of the submerged prehistoric landscape in ground-truthing models of human dispersal during the last half million years. In *Under the Sea: Archaeology and Palaeolandscapes of the Continental Shelf. Coastal Research Library 20,* Bailey GN *et al.* (eds). Dordrecht: Springer; 269–283.

Fujita M, Yamasaki S, Katagiri C *et al.* 2016. Advanced maritime adaptation in the western Pacific coastal region extends back to 35,000-30,000 years before present. *Proceedings of the National Academy of Sciences of the United States of America* **113**: 11184–11189.

Gao X. 1999. A discussion of the Chinese Middle Palaeolithic. *Acta Anthropologica Sinica* **18**: 1–16 [in Chinese with English abstract].

Gao X, Norton CJ. 2002. A critique of the Chinese 'Middle Palaeolithic'. *Antiquity* **76**: 397–412.

Grimm EC. 1990. TILIA and TILIA*GRAPH.PC spreadsheet and graphics software for pollen data *INQUA, Working Group on Data-Handling Methods. Newsletter* **4**: 5–7.

Groucutt HS, Petraglia MD, Bailey G *et al.* 2015. Rethinking the dispersal of *Homo sapiens* out of Africa. *Evolutionary Anthropology* **24**: 149–164.

Hu L-r. 2004. Study on mammal fossils found in Zhoushan Sea area. *Journal of Zhejiang Ocean University (Natural Science)* **23**: 218–221 [in Chinese with English abstract].

Jerardino A, Marean CW. 2010. Shellfish gathering, marine paleoecology and modern human behavior: perspectives from cave PP13B, Pinnacle Point, South Africa. *Journal of Human Evolution* **59**: 412–424.

Klein RG, Steele TE. 2013. Archaeological shellfish size and later human evolution in Africa. *Proceedings of the National Academy of Sciences of the United States of America* **110**: 10910–10915.

Kyriacou K, Parkington JE, Marais AD *et al.* 2014. Nutrition, modernity and the archaeological record: coastal resources and nutrition among Middle Stone Age hunter-gatherers on the western Cape Coast of South Africa. *Journal of Human Evolution* **77**: 64–73.

Lambeck K, Rouby H, Purcell A *et al.* 2014. Sea level and global ice volumes from the Last Glacial Maximum to the Holocene. *Proceedings of the National Academy of Sciences* **111**: 15296–15303.

Langley MC, O'Connor S, Piotto E. 2016. 42,000-year-old worked and pigment-stained Nautilus shell from Jerimalai (Timor-Leste): evidence for an early coastal adaptation in ISEA. *Journal of Human Evolution* **97**: 1–16.

Li F, Bae CJ, Ramsey CB *et al.* 2018. Re-dating Zhoukoudian Upper Cave, northern China and its regional significance. *Journal of Human Evolution* **121**: 170–177.

Li J. 1991. The environmental effects of the uplift of the Qinghai-Xizang Plateau. *Quaternary Science Reviews* **10**: 479–483.

Li X, Du N. 1999. The acid-alkali-free analysis of Quaternary pollen. *Acta Botanica Sinica* **41**: 782–784.

Liu J-y, Fu R-y. 1997. Quaternary mammals found in Bohai Strait. *Journal of Liaohai Relics* **2**: 18–19 [in Chinese].

Liu W, Jin CZ, Zhang YQ *et al.* 2010. Human remains from Zhirendong, South China, and modern human emergence in East Asia. *Proceedings of the National Academy of Sciences of the United States of America* **107**: 19201–19206.

Liu W, Martinón-Torres M, Cai Y-j *et al.* 2015. The earliest unequivocally modern humans in southern China. *Nature* **526**: 696–699.

Long H, Haberzettl T, Tsukamoto S *et al.* 2015. Luminescence dating of lacustrine sediments from Tangra Yumco (southern Tibetan Plateau) using post-IR IRSL signals from polymineral grains. *Boreas* **44**: 139–152

Macaulay V, Hill C, Achilli A *et al.* 2005. Single, rapid coastal settlement of Asia revealed by analysis of complete mitochondrial genomes. *Science* **308**: 1034–1036.

Marean CW. 2014. The origins and significance of coastal resource use in Africa and western Eurasia. *Journal of Human Evolution* **77**: 17–40.

Marean CW, Bar-Matthews M, Bernatchez J *et al.* 2007. Early human use of marine resources and pigment in South Africa during the Middle Pleistocene. *Nature* **449**: 905–908.

Mellars P. 2006. Going east: new genetic and archaeological perspectives on the modern human colonization of Eurasia. *Science* **313**: 796–800.

Michel V, Valladas H, Shen G *et al.* 2016. The earliest modern Homo sapiens in China? *Journal of Human Evolution* **101**: 101–104.

Mijares AS, Détroit F, Piper P *et al.* 2010. New evidence for a 67,000-year-old human presence at Callao Cave, Luzon, Philippines. *Journal of Human Evolution* **59**: 123–132.

Moore PD, Webb JA. 1978 Illustrated Guide to Pollen Analysis. *New York: Hodder & Stoughton.*

Murray AS, Wintle AG. 2003. The single aliquot regenerative dose protocol: potential for improvements in reliability. *Radiation Measurements* **37**: 377–381.

Nian X-m, Chen F-y, Li F *et al.* 2015. Optical dating of a Paleolithic site near the eastern coastal region of Shandong, northern China. *Quaternary Geochronology* **30**: 466–471.

O'Connor S, Ono R, Clarkson C. 2011. Pelagic fishing at 42,000 years before the present and the maritime skills of modern humans. *Science* **334**: 1117–1121.

Parkington J. 2010. Coastal diet, encephalization, and innovative behaviors in the late Middle Stone Age of southern Africa. In *Human Brain Evolution: the Influence of Freshwater and Marine Food Resources*, Cunnane SC, Stewart KM (eds). Hoboken: Wiley-Blackwell 189–203.

Parkington JE. 2001. Milestones: the impact of systematic exploitation of marine foods on human evolution. In *Humanity from African Naissance to Coming Millenia*, Tobias PV, Raath MA, Moggi-Cechi J, Doyle GA (eds). Florence: Firenze University Press; 327–336.

Parkington JE. 2003. Middens and moderns: shellfishing and the Middle Stone Age of the Western Cape, South Africa. *South African Journal of Science* **99**: 243–247.

Pei W-c. 1939. On the Upper Cave industry. *Palaeonotologica Sinica* **9**: 1–59.

Peng F, Fan X-c. 2008. Study on the human modification of the fauna assemblages found in Taiwan Strait. *Archaeological Study* **7**: 506–518 [in Chinese].

Petraglia MD, Haslam M, Fuller DQ *et al.* 2010. Out of Africa: new hypotheses and evidence for the dispersal of *Homo sapiens* along the Indian Ocean rim. *Annals of Human Biology* **37**: 288–311.

Qi G-q, Ho C-k. 1999. Quaternary fauna and paleogeography in Penghu Trench of Taiwan. *Quaternary Sciences* **19**: 185 [in Chinese].

Rohling EJ, Foster GL, Grant KM *et al.* 2014. Sea-level and deep-sea-temperature variability over the past 5.3 million years. *Nature* **508**: 477–482.

Shang H, Tong H, Zhang S *et al.* 2007. An early modern human from Tianyuan cave, Zhoukoudian, China. *Proceedings of the National Academy of Sciences of the United States of America* **104**: 6573–6578.

Shi X, Yao Z, Liu Q *et al.* 2016. Sedimentary architecture of the Bohai Sea China over the last 1 Ma and implications for sea-level changes. *Earth and Planetary Science Letters* **451**: 10–21.

Siddall M, Rohling EJ, Almogi-Labin A *et al.* 2003. Sea-level fluctuations during the Last Glacial Cycle. *Nature* **423**: 853–858.

Song Y-h, Shi J-m. 2013. The study of ornaments from the Shizitan Paleolithic site in Jixian county, Shanxi Province. *Archaeology* **8**: 46–57 [in Chinese with English abstract].

Stiner MC. 1994. *Honor among thieves: a zooarchaeological study of Neandertal ecology*. Princeton, NJ: Princeton Unversity Press.

Stringer C. 2000. Palaeoanthropology. *Coasting out of Africa. Nature* **405**: 138.

Stringer CB, Finlayson JC, Barton RNE *et al.* 2008. Neanderthal exploitation of marine mammals in Gibraltar. *Proceedings of the National Academy of Sciences of the United States of America* **105**: 14319–14324.

Sun X-j, Li X, Luo Y-l *et al.* 2000. The vegetation and climate at the last glaciation on the emerged continental shelf of the South China Sea. *Palaeogeography, Palaeoclimatology, Palaeoecology* **160**: 301–316.

Sun X-j, Luo Y-l, Huang F *et al.* 2003. Deep-sea pollen from the South China Sea: Pleistocene indicators of East Asian monsoon. *Marine Geology* **201**: 97–118.

Sun Y-f, Wang H, Liu J-y. 1992. On a new subspecies of *Bos primigenius* found on the bottom of Bohai Sea and Yellow Sea. *Liaoning Geology* **2**: 163–166 [in Chinese with English abstract].

Waelbroeck C, Labeyrie L, Michel E *et al.* 2002. Sea-level and deep water temperature changes derived from benthic foraminifera isotopic records. *Quaternary Science Reviews* **21**: 295–305.

Wang J, Zhou X-y, Long H *et al.* 2018. Late Pleistocene environmental background of human occupations of the Dazhushan Paleolithic site in Qingdao, Shandong, China. *Acta Anthropologica Sinica* **37** (e): 170–182 [in Chinese with English abstract].

Wang J-t, Wang P-x. 1980. Relationship between sea-level changes and climatic fluctuations in East China since Late Pleistocene. *Acta Geographica Sinica* **35**: 299–312 [in Chinese with English abstract].

Wang P-x, Min Q-b, Bian Y-h *et al.* 1981. Strata of Quaternary transgressions in East China: a preliminary study. *Acta Geologica Sinica* **1**: 1–13 [in Chinese with English abstract].

Wang Z, Zhuang C, Saito Y *et al.* 2012. Early-mid-Holocene sea-level change and coastal environmental response on the southern Yangtze Delta plain, China: implications for the rise of Neolithic culture. *Quaternary Science Reviews* **35**: 51–62.

Will M, Kandel AW, Kyriacou K *et al.* 2016. An evolutionary perspective on coastal adaptations by modern humans during the Middle Stone Age of Africa. *Quaternary International* **404**: 68–86.

Wu C, Zhang Y, Li Q *et al.* 2011. An environmental database and temporal and spatial distribution of Chinese paleoanthropological sites. *Chinese Science Bulletin* **56**: 3281–3283.

Wu L, Zhu C, Zheng C *et al.* 2014. Holocene environmental change and its impacts on human settlement in the Shanghai Area, East China. *CATENA* **114**: 78–89.

Wu X-h, Zhang C, Goldberg P *et al.* 2012. Early pottery at 20,000 years ago in Xianrendong Cave, China. *Science* **336**: 1696–1700.

You Y-z, Dong X-r, Cai B-q *et al.* 1995. Mammalian fossils from western Taiwan Strait. *Vertebrata PalAsiatica* **33**: 231–237 [in Chinese with English abstract].

You Y-z, Xu X-l, Yuan X-f *et al.* 1989. Paleolithic implications from the coastal area in Rizhao, Shandong Province. *Acta Anthropologica Sinica* **8**: 101–106 [in Chinese with English abstract].

Yuan J. 1995. Issues on research on shell mound sites in mainland China. *Archaeology* **12**: 1100–1109 [in Chinese].

Yuan J, Liang Z-h, Wu Y *et al.* 2002. Shell mounds in the Jiaodong Peninsula: a study in environmental archaeology. *Journal of East Asian Archaeology* **4**: 1–26.

Zheng H, Zhou Y, Yang Q *et al.* 2018. Spatial and temporal distribution of Neolithic sites in coastal China: sea level changes, geomorphic evolution and human adaption. *Science China Earth Sciences* **61**: 123–133.