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Diachronic Change in the Utilization of Ostrich Eggshell at the Late Paleolithic Shizitan Site, North China

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Forty-one ostrich eggshell (OES) artifacts excavated at five localities of the late Paleolithic Shizitan site, on the North China Loess Plateau, allow the observation of diachronic changes in the utilization of ostrich eggs in the production and use of ornaments considered to be technologies of social signaling, beginning during the Last Glacial Maximum (LGM) and continuing through the Younger Dryas. Based on changes in dimensions, production techniques such as drilling, coloration through heat treatment or the application of ochre, and stringing techniques, the OES pendant and bead use at Shizitan is divided into four phases. Phases 1–3 feature only completed ornaments, usually with heavy usewear. Only in Phase 4, during the Younger Dryas, blanks and drilled preforms are found that indicate local production. While Phase 1 features the use of larger pendants colored grey/black by burning, subsequent phases see beads replacing pendants, no heat coloration, and the use of the ochre pigment. The switch to beads corresponds with the change to microblade technology at Shizitan 29. Phase 3 shows a trend toward a larger relative surface display area and maturation of techniques to produce visual effects of roundedness and weightiness. Phase 4 local production shows technological developments that allowed drilling smaller apertures while also decreasing the bead diameter and increased standardization, implying changing display objectives (stringing beads together with a uniform appearance). The changes observed in the Shizitan diachronic dataset may relate to changing requirements in social signaling—part of the adaptations the hunter–gatherer groups made to survive the challenges of climatic change from the LGM through the Terminal Pleistocene in North China.

Keywords: ostrich eggshell, non-edible utilization, perforated ornaments, ornament coloration, drilling techniques, social signaling, Last Glacial Maximum, Shizitan site localities

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INTRODUCTION

The use of ostrich eggshell as a raw material for Paleolithic mobile hunter–gatherer artifact production is well-documented in regions then inhabited by ostriches, particularly in Late Stone Age contexts in Africa and Upper (or Late) Paleolithic contexts in northern Asia (Wingfield, 2003; Hitchcock, 2012). The most common, but still rare, usage known is for making personal ornaments—non-utilitarian items in the form of drilled beads or pendants that are interpreted as aesthetic items that hold a symbolic value and may function as technologies of communication and social signaling (Kuhn S. and Stiner, 2007; Kuhn S. L. and Stiner M. C., 2007; Kuhn, 2014; Stiner, 2014) or in reinforcing hunter–gatherer reciprocity networks, particularly in times of stress (Vanhaeren, 2005). Other ostrich eggshell items could have held similar roles, such as abstract representations engraved on ostrich eggshell,a form of portable art (Miller and Willoughby, 2014). Ostrich eggshell (OES) ornaments have been reported from sub-Saharan African Late Stone Age and possibly Middle Stone Age contexts (e.g., Deacon, 1995; Robbins et al., 2000; Vogelsang et al., 2010; d'Errico et al., 2012), and East African sites (perhaps first appearing 50–39 ka BP) (e.g., Mehlman, 1991; Miller and Willoughby, 2014), and sites in North Asia by 37 ka cal BP (or perhaps earlier), including Siberia (Denisova Cave in the Russian Altai), Mongolia (Tobor 4, Tolbor 16, and Dörölj 1), and the Transbaikal region (at Podzvonkaya localities) (Tashak, 2002a; Tashak, 2002b; Jaubert et al., 2004; Derevianko et al., 2006; Kuzmin et al., 2011; Mellars et al., 2013; Rybin, 2014; Zwyns et al., 2014; Wei et al., 2017). Where appropriate data are available, the archaeological distributions beginning from ca. 50 ka BP of such non-edible animal resources as OES can be taken as indicators of mobility patterns or the social geography of modern humans or used in models of diffusion and exchange through social networks (e.g., Mcbrearty and Brooks, 2000; Stiner, 2014; Abadía and Nowell, 2015; Stewart et al., 2020 and references therein).

In China, ostrich (*Struthio* sp.) eggshell ornaments are rare but are found beginning from ca. 34 Ka cal BP at Upper, or "Late", Paleolithic sites in North China, including localities of the Shuidonggou site (Chen et al., 2012; Gao et al., 2013; Pei et al., 2014; Wang et al., 2015) and the Gezishan site (Guo et al., 2017) in Ningxia, the Shizitan site in Shanxi (Shizitan Archaeological Team, 2010; Shizitan Archaeological Team, 2013; School of History and Culture, Shanxi University and Shanxi Provincial Institute of Archaeology, 2017; Song et al., 2017), and at Xishahe (Guan et al., 2020) and other localities in the Nihewan Basin in Hebei (Chen et al., 2012; Gao et al., 2013; Pei et al., 2014).

At Shuidonggou localities SDG 2, 7, and 8, OES ornaments are found in "advanced core and flake" contexts from ca. 34–27 Ka cal BP (Li et al., 2019), along with the usage of stone grinding slabs, bone needles, and ochre pigment. Shuidonggou 2 features six OES beads artificially colored with an ochre pigment compound, found in a layer dating 31 Ka cal BP (Pitarch Martí et al., 2017). At the Xishahe locality in the Nihewan Basin, OES fragments are found in an early occupation layer (3B), with one piece directly radiocarbon dated to ca. 29 Ka cal BP, and one biconically drilled ostrich shell bead fragment was recovered from the earliest microblade-producing level (3A), dating ca. 27 Ka cal BP, which is one of the earliest microblade contexts in North China (Guan et al., 2020). Similarly, at Shizitan, OES ornaments are first produced in "advanced core and flake" industry contexts and continue to be in use when microblade production begins at Shizitan 29 during the Last Glacial Maximum, between 26 and 24 Ka cal BP (Song et al., 2017). Below, we discuss the development of the OES ornament productions at Shizitan, which continues through the Terminal Pleistocene. Because of the overall scarcity of all ornament types in Paleolithic North China, including OES ornaments, or any other preserved material culture related to symbolic behavior, communication, and art and behavioral modernity (see Bar-Yosef, 2007), the OES data set from the controlled excavations of seven contexts across five localities at Shizitan spanning in time from the LGM through the Younger Dryas give unique insight into ornament usage during this time period of significant climate changes not represented by other sites. This study serves as a descriptive introduction to the characteristics of the Shizitan ornaments and trends in their production and usage over time, which we divide into four distinct phases representing changes in hunter–gatherer choices and preferences in the use of these symbolic objects. This initial presentation may lead to further experimental and comparative studies and raise awareness of the potential of the North China dataset in understanding Late Paleolithic behavior and adaptations.

Late Paleolithic sites in North China have long been known to produce forms of personal ornamentation other than OES beads. Excavations in 1933–34 at the Zhoukoudian Upper Cave near Beijing revealed burials of eight modern human individuals and pendants of perforated animal teeth, mollusk shell, fishbone, and stone (Li et al, 2018). Although the dating of the Zhoukoudian Upper Cave burials is debated (ranging between 35 and 10 Ka cal BP), Li Feng et al. (2018: 174) note that all other such examples of perforated ornaments in China date after 34 Ka cal BP. Subsequent discoveries of personal ornamentation in China (Li and Huo, 1990; Pei, 1999; Wang et al., 2012; Ma, 2016; Wei et al., 2017; Wei et al., 2017; Li et al, 2018; Wei and Gao, 2020) lead to an overall understanding concerning the origin and development of ornaments made of freshwater and marine mollusk shell, OES, bone, teeth, stone, and other materials in the Late Paleolithic period. Research over the past decade on OES ornaments has focused on three sites because they have undergone controlled excavations, namely, Shizitan (Song et al., 2011; Song and Shi, 2013a; Song and Shi, 2013b), Shuidonggou (Wang et al., 2009; Wang, 2010; Wang et al., 2011; Wei et al., 2017), and Yujiagou (Nihewan Basin) (Wang et al., 2020). This work has included studies on the origins of OES products, manufacturing techniques and sequences (Song and Shi, 2013a; Song and Shi, 2013b), and related experimental archaeology (Wei et al., 2017; Wei and Gao, 2020) and follows upon previous such work carried out primarily on materials from African sites (e.g., Kandel and Conard, 2005; Orton, 2008; Miller and Willoughby, 2014; Collins and Steele, 2017; Werner and Miller, 2018; Craig et al., 2020).

MATERIALS AND METHODS

This descriptive study is based on observations and measurement of the Shizitan site data set of OES ornaments, the purpose of which is to introduce initial observations and hypotheses concerning diachronic changes in the production and display of these objects. Characterizations of technology (e.g., cutting, drilling, polishing, and color alteration) and usewear are derived from sources cited below that present experimental studies on OES and observations of archaeological objects. Classification, measurements, and observations of color alteration for 41 pieces

TABLE 1 | OES ornament counts, contexts, and associated radiocarbon dating at Shizitan localities.

Locality	Layer	Lab no	14C sample materials	Dates[a]	OES pendants	OES beads			Total	References
						Finished	Semi-finished	Fragments		
SZT9	Layer 4	—	Charcoal	12,756–11,350	—	2	4	5	11	Shizitan Archaeological Team, (2010)
SZT12G	—	BA121964	Burnt bone	15,987–15,394 (95.4%)	—	1	—	—	1	Unpublished
SZT1	Lower cultural layer	—	Bone	35,100–17,000	—	—	—	2	2	Yuan et al. (1998)
SZT24	—	BA04008	Bone	20,460–19,960 (95.4%)	1	—	—	—	1	Song and Shi. (2013a), Song and Shi. (2013b)
SZT29	Layer 2	BA101414	Bone	18,059–17,505 (95.4%)	—	2	—	—	26	Song et al. (2017)
	Layer 7 Upper contact	—	Charcoal and burnt bone	Later stage of 26,000–24,000	—	1	—	—	—	—
	Layer 7 Top	—	—	—	—	4	—	—	—	—
	Layer 7 spits 5–2	—	—	Early stage of 26,000–24,000	19	—	—	—	—	—
Total	—	—	—	—	20	10	4	7	41	—

[a]*Notes: Date ranges without lab numbers are estimated based on multiple, calibrated AMS. ^{14}C dates from the same layer. Shizitan 1 dating is a broad estimate. The SZT12G date may not be reliable: we estimate this layer to date later, roughly contemporaneous with SZT9 layers 4–5.*

of OES ornaments (categorized as pendants or beads), blanks, and raw material from five localities of the Shizitan site (SZT 29, 24, 1, 12G, and 9) and seven distinct stratigraphic contexts within them (described separately below) are tabulated for the purpose of determining potential trends in changes in ornament size, production, function, use, and preference over a 15,000 year period from the Last Glacial Maximum through the Younger Dryas (see **Tables 1**, **2**). For details on previous studies of Shizitan OES ornament production and usewear, including experimental studies, see Song and Shi (2013a), Song and Shi (2013b).

Classification

Most of the OES materials from the Shizitan localities are finished products (with the exception of blanks and raw material from Shizitan 9 during the last phase of occupation of Shizitan). We classify these objects with central apertures for stringing into “beads” and “pendants.” This classification, which size classes also align with (pendants tend to be larger), is based primarily on evidence for the stringing or suspension technique, observed through usewear and experiment in previous studies (Song and Shi 2013a; Song and Shi, 2013b). The OES products classified as pendants have usewear on one quadrant of the ornament’s OES exterior and interior faces left from individually tying the ornament with a knot or hitch there so that they would be suspended at what then becomes the top of the pendant: this also leaves the exterior or interior shell surface “face” of the object maximally visible (Song and Shi, 2013a). Beads are objects with a central perforation (bead hole) and lack this sort of usewear. Beads were likely strung in groups, with stringing penetrating through the central holes of a set of ornaments, in which case the flat interior or exterior OES surface would not be as visible as with strung pendants.

Measurement

Measurements were made for external diameter, aperture diameter, “body width”, and thickness. We define “body width” as the distance from the hole wall to the exterior edge of the ornament. Because the ornaments’ outer circumference and aperture (central perforation) are not perfectly round, either because of how they were manufactured or due to uneven usewear, the measurements given in **Tables 1**, **2** are averages, made as follows: for beads, four body width measurements were taken, once every 90° around the object, and the average is used; the aperture diameter is the average of four measurements, each every 45°. For pendants, which we define as ornaments suspended from their upper part, because there is heavy usewear on almost all of them from stringing and polishing causing loss of the body diameter from top to bottom and widening of the aperture from wear at the top of the hole wall (from where the pendant had been suspended by stringing), the body width measurements are an average of two values, measured at 90 and 270° around the diameter, and the aperture diameter is measured across this same line.

Color and Heating

Color is observed by naked eye and indicated using general terminology. Based on previous studies of OES heat treatment and post-depositional changes cited below, we infer that color changes were brought about primarily by heat treatment, likely due to exposure to open fire, which is also supported by observations of surface changes such as crackling, but this must be tested and experimented further across all OES data sets as the particular processes by which some color changes occur still remain unknown, such as for the black color found at Shizitan (Collins and Steele, 2017). For Shizitan, a series of

TABLE 2 | Measurements (in mm) of the OES ornaments from Shizitan site localities SZT29, 24, 12G, and 9. Body width (BW) = distance from the hole wall to exterior edge.

Locality	Object no. or context	Depth below site datum (cm)	External diameter	Aperture diameter (AD)	Body width (BW)	BW/ AD	Thickness	Notes	Type	Color	Notes
SZT9 Layer 4	Spit 2	250–255	3.43	—	—	—	2.2	Fragment	Bead	Ivory	**Figure 2**: 7; **Figure 5**: 9
	Spit 3	255–260	4.29	1.31	1.4	1.07	2.10	Two-sided perforated	Bead	Ivory	**Figure 2**: 1; **Figure 5**: 1
	Spit 4	260–268	5.67	1.23	—	—	2.10	One-sided drilling	Bead	Ivory	**Figure 2**: 4; **Figure 5**: 4
	Spit 5	268–274	3.80	1.14	1.4	1.23	2.05	Two-sided perforated	Bead	Ivory	**Figure 2**: 2; **Figure 5**: 2
	Spit 6	274–280	5.67	0.99	—	—	2.10	Two-sided drilling	Bead	Ivory	**Figure 2**: 3; **Figure 5**: 3
	Spit 10	295–305	6.40	1.38	—	—	1.20	Burnt fragment, one-sided drilling	Bead	Black	**Figure 2**: 6; **Figure 5**: 5
	Spit 10	295–305	4.07	—	—	—	2.03	Fragment	Bead	Ivory	**Figure 2**: 8; **Figure. 5**: 11
	Spit 11	305–310	4.92	1.48	—	—	2.10	One-sided drilling	Bead	Ivory	**Figure 2**: 5; **Figure 5**: 6
	Spit 11	305–310	5.33	—	—	—	2.62	Fragment	Bead	Ivory	**Figure 2**: 9; **Figure 5**: 8
	Spit 12	310–316	4.34	—	—	—	2.3	Fragment	Bead	Ivory	**Figure. 2**: 10; **Figure 5**: 10
	Spit 14	323–330	6.02	—	—	—	1.9	Fragment	Bead	Ivory	**Figure 2**: 11; **Figure 5**: 7
—	Mean	—	4.05	1.23	1.4	1.15	2.08	Includes only perforated ones	—	—	—
SZT12G	1853	124.9	5.57	2.12	1.7	0.80	2.13	Used	Bead	Ivory	**Figure 2**: 12; **Figure 4**: 1
SZT24	307	48.6	9.43	2.61	—	—	1.31	Used	Pendant	Ivory	**Figure 2**: 13; **Figure 3**: 20
SZT29 Layer 2	1836	162	7.46	2.89	2.1	0.73	2.01	Used	Bead	Ivory	**Figure 2**: 14; **Figure 4**: 3
	13,864	Collected	8.74	4.01	2.4	0.60	1.70	Used	Bead	Ivory	**Figure 2**: 15; **Figure 4**: 2
—	Mean	—	8.1	3.45	2.25	0.67	1.86	—	—	—	—
SZT29 Layer 7 Upper Contact	72–76	1,145–1,150	7.57	3.4	2.4	0.71	1.81	Remnant half	Bead	Ivory	**Figure 2**: 16; **Figure 4**: 4
SZT29Layer 7 Spits 2–1[a]	13846	1,147–1,154	5.71	2.60	1.6	0.62	1.36	Used	Bead	Ivory	**Figure 2**: 19; **Figure 4**: 5
	13847	1,147–1,154	5.41	2.70	1.3	0.48	1.29	Used	Bead	Ivory	**Figure 2**: 20; **Figure 4**: 6
	1348	1,147–1,154	5.39	2.67	1.4	0.52	0.98	Used	Bead	Ivory	**Figure 2**: 18; **Figure 4**: 7
	70–92	1,189–1,190	5.55	2.88	1.2	0.42	1.30	Used	Bead	Ivory	**Figure 2**: 17; **Figure 4**: 8
—	Mean	—	5.52	2.71	1.38	0.51	1.23	—	—	—	—
SZT29 Layer 7 Spits 5–2	13,849	1,149–1,170	12.64	2.22	5.3	2.39	1.53	Used	Pendant	Black	**Figure 2**: 21; **Figure 3**: 1
	13850	1,159.5	10.12	2.85	3.6	1.26	1.69	Used	Pendant	Black	**Figure 2**: 22; **Figure 3**: 14
	13852	1,150–1,170	9.30	—	—	—	1.43	Fragment, used	Pendant	Black	**Figure 2**: 23; **Figure 3**: 3
	64–97	1,150–1,170	11.43	—	—	—	1.8	Fragment, used	Pendant	Black	**Figure 2**: 36; **Figure 3**: 19
	66–106	1,170–1,180	11.13	—	—	—	1.89	Fragment, used	Pendant	Gray	**Figure 2**: 38; **Figure 3**: 16
	13851	1,170–1,180	10.37	3.79	3.6	**0**.91	1.72	Used	Pendant	Black and Gray	**Figure 2**: 24; **Figure 3**: 4
	13853	1,180–1,190	10.89	2.89	3.7	1.28	1.96	Used	Pendant	Black	**Figure 2**: 25; **Figure 3**: 5
	13854	1,180–1,190	11.47	2.73	4.5	1.65	1.89	Used	Pendant	Black	**Figure 2**: 26; **Figure 3**: 6

(Continued on following page)

TABLE 2 | (*Continued*) Measurements (in mm) of the OES ornaments from Shizitan site localities SZT29, 24, 12G, and 9. Body width (BW) = distance from the hole wall to exterior edge.

Locality	Object no. or context	Depth below site datum (cm)	External diameter	Aperture diameter (AD)	Body width (BW)	BW/ AD	Thickness	Notes	Type	Color	Notes
	13855	1,180–1,190	10.86	2.95	4.0	1.36	1.69	Used	Pendant	Black	**Figure 2**: 27; **Figure 3**: 2
	13856	1,180–1,190	12.13	2.94	4.5	1.53	2.08	Used	Pendant	Black and Gray	**Figure 2**: 28; **Figure 3**: 8
	13857	1,180–1,190	12.25	3.11	4.4	1.41	2.05	Used	Pendant	Gray	**Figure 2**: 29; **Figure 3**: 9
	80–103	1,180–1,190	9.82	—	—	—	1.7	Fragment, used	Pendant	Black	**Figure 2**: 39; **Figure 3**: 17
	81–109	1,180–1,190	7.46	—	—	—	1.57	Fragment, used	Pendant	Black	**Figure 2**: 37; **Figure 3**: 18
	13858	1,200–1,210	12.54	—	—	—	2.13	Fragment, used	Pendant	Black	**Figure 2**: 30; **Figure 3**: 10
	13859	1,200–1,210	9.82	—	—	—	2.02	Fragment, Used	Pendant	Gray	**Figure 2**: 31; **Figure 3**: 11
	13860	1,210–1,220	11.13	2.03	4.7	2.32	2.29	Used	Pendant	Black and gray	**Figure 2**: 32; **Figure 3**: 12
	13861	1,210–1,220	12.88	2.91	5.1	1.75	1.85	Used	Pendant	Black	**Figure 2**: 33; **Figure 3**: 13
	13862	1,210–1,220	11.28	2.94	4.3	1.46	1.75	Used	Pendant	Black and gray	**Figure 2**: 34; **Figure 3**: 7
	13863	1,210–1,220	10.52	—	—	—	0.56	Fragment, used	Pendant	Black	**Figure 2**: 35; **Figure 3**: 15
—	Mean	—	11.46	2.85	—	1.57	1.86	Fragments not included	—	—	—

[a]*Note: The beads in SZT29 Layer 7 Spits 2-1 were over-drilled, meaning the conchoidal hole opening extended through the bead edge, which causes loss of the OES's original thickness.*

planned experiments are ongoing to verify particular color changes in OES under different conditions (heat from flame vs. boiling, tracking time and temperature).

SHIZITAN SITE ARCHAEOLOGICAL CONTEXTS

The Shizitan site is composed of at least 30 open-air site localities located along the present-day Qingshui River (a perennial tributary of the Yellow River), in Jixian County, Shanxi Province, on the North China Loess Plateau (**Figure 1**). First discovered in 1980, and with several localities excavated between 2000 and 2010, the sequence for the site, ranging from ca. 30 to 8.5 Ka cal BP, is best represented at excavated localities SZT29 and SZT9, which have contexts extending from before and during the Last Glacial Maximum (LGM) and through the Younger Dryas (YD) into the Early Holocene, with correlating changes in their Late Paleolithic material cultural records (Shizitan Archaeological Team, 2010; Song et al., 2017; Song et al., 2019).

Late Paleolithic remains at Shizitan include more than 300 hearths and tens-of-thousands of artifacts, including lithics, grinding slabs and handstones (Liu et al., 2011; Liu et al., 2013), ochre pigments, polished bone needles (Song et al., 2016), and ornaments made of bivalve shell and ostrich eggshell. The localities provide a record of human adaptations to the challenging local conditions of the Loess Plateau through the Last Glacial period, including the LGM (when microblade production begins) and YD.

Here, we discuss the forty-one pieces of identified ostrich eggshell from five localities, SZT1, SZT9, SZT12G, SZT24, and SZT29 (**Figure 1**). Counts and dating based on calibrated radiocarbon dates from cultural layers at the localities are provided in **Table 1**.

Shizitan 29

Shizitan locality 29 (36°2′54″N, 110°35′22″E, 723 masl) is located about 500 m east of Shizihe Village of Jixian County. It was excavated from 2009 to 2010. The 1,200 m^2 excavation area features a 15 m deep depositional sequence with eight "cultural layers" (Level 8 is the lowest, dating ca. 28 Ka cal BP) typically interspersed with geological layers with few artifacts and no evidence of anthropogenic inputs. It is an open-air site thought to be ephemerally but repeatedly occupied by hunter–gatherers over its history. A total of 285 hearths were excavated in Layers 1 through 7 (Song et al., 2017; School of History and Culture, Shanxi University and Shanxi Provincial Institute of Archaeology, 2017). Among more than 80,000 artifacts, 26 OES ornaments were excavated in Layers 7 (**Figures 2**: 16–39) and 2 (**Figure 2**: 14, 15), including six identified after the reports in 2013 and 2017 (Song and Shi, 2013a; Song and Shi, 2013b; Song, 2013; Song et al., 2017) (**Figure 2**: 16, 17, 36–39).

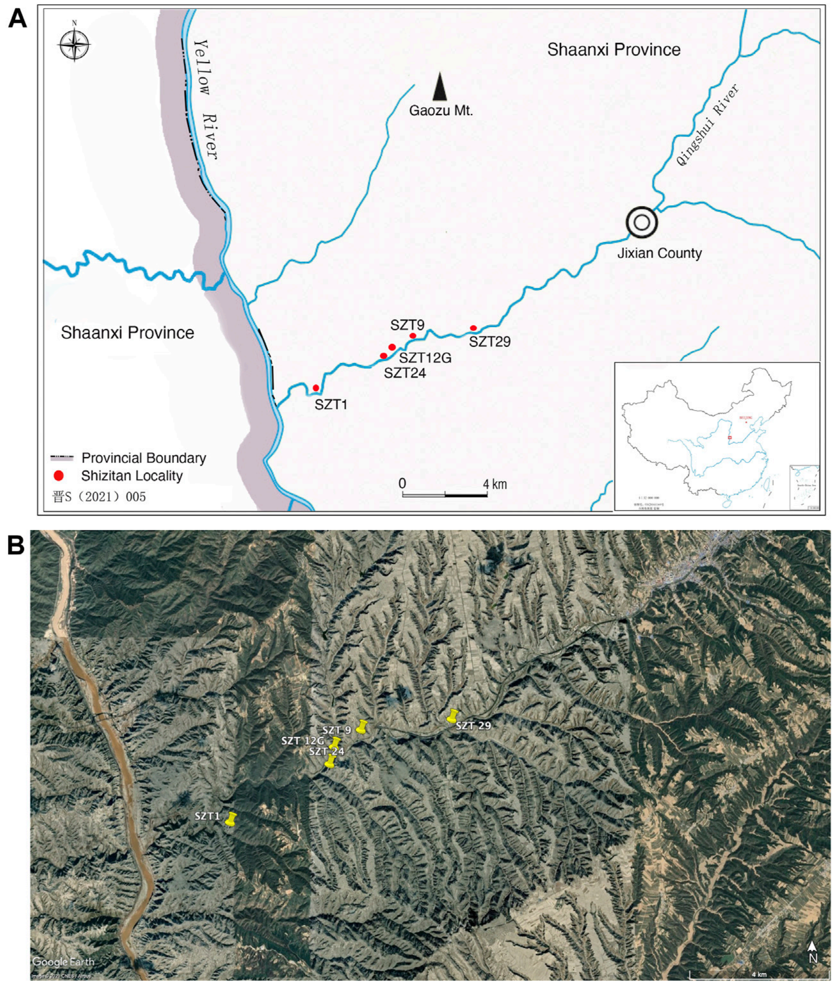

FIGURE 1 | (A) Map showing the locations of the excavated Shizitan localities with OES ornaments, along the Qingshui River, Shanxi Province. **(B)** Google Earth satellite image showing the positions of the Shizitan localities within the Loess Plateau landscape.

The earliest OES ornaments at SZT29 are found in Layer 7, dating between ca. 26–24 Ka cal BP. Layer 7 reflects the onset of colder and drier conditions during the LGM (Song et al., 2017). Song et al. (2019) divide Layer 7 into two stratigraphical sampling units based on the excavated 10 cm spits in order to investigate a major lithic technological change: "Layer 7 Base" represents the earlier "advanced core and flake industry" in spits 7–12 that continued from Layer 8, and "Layer 7 Top" represents spits 1–2, where microblade production replaces the earlier core and flake industry (and is one of the earlier true microblade pressure productions in North China) (Song et al., 2019). The earliest OES pendants at SZT29 appear in Layer 7 Spits 5–2: it is not clear if they appear before a limited amount of microblade technology is present at the site. In spits 1–2, however, the earliest OES beads are found in what is clearly the first microblade industry context.

Layer 7 Spits 5–2, as shown in **Table 1**, produced 19 perforated OES items identifiable as personal ornamentation (**Figure 2**: 21–39; **Figure 3**: 1–19). Measurement data excludes eight broken/partial pieces. The average diameter of the perforated pieces is 11.46 (9.3–12.88) mm, thickness 1.86 (1.43–2.29) mm, and aperture diameter 2.85 (2.03–3.79) mm (**Table 2**). In this study, the term "perforating" is used generally to refer to purposefully working a hole through the item as a stage in the manufacturing process. Where evidence indicates that an aperture was made though drilling, we specifically mention this. Werner and Miller (2018), in their study of drilling techniques, distinguish perforating (which would include holes made by pecking, gouging, or punching) from rotary drilling, which is actually the technique used on the vast majority of African Stone Age OES beads they observed. We suggest the same may hold for North China OES, but further observation and experimentation are needed that are outside the scope of this initial, descriptive study.

The ornaments from Layer 7 Spits 5–2, thus, show relative uniformity in size, and they are the largest-sized examples of OES ornaments across all Shizitan localities. An important trait of these 19 ornaments is their color. Their black gray or half black/

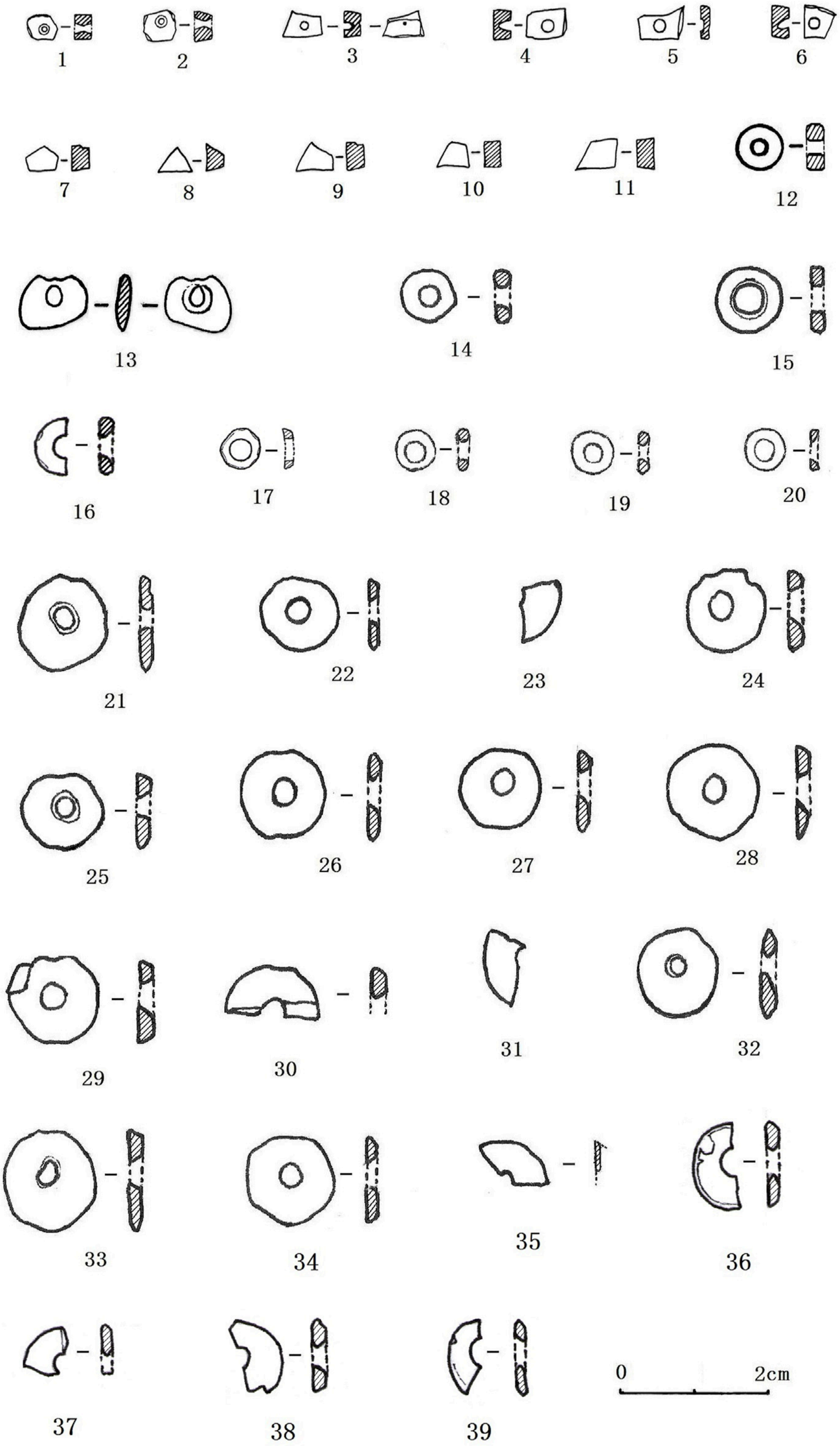

FIGURE 2 | Perforated OES ornaments identified at localities of the Late Paleolithic Shizitan site. 1, 2. Perforated beads from SZT9 Layer 4; 3–6. Semi-perforated beads from SZT9 Layer 4; 7–11. Broken pieces from SZT9 Layer 4; 12. Used bead from SZT12G; 13. Heavily used pendant from SZT24; 14–15. Used beads from SZT29 Layer 2; 16. Used bead from SZT29, Layer 7 upper contact; 17–20. Used beads from SZT29 Layer 7 Spits 2–1; 21–39. Used pendants from SZT29 Layer 7 Spits 5–2.

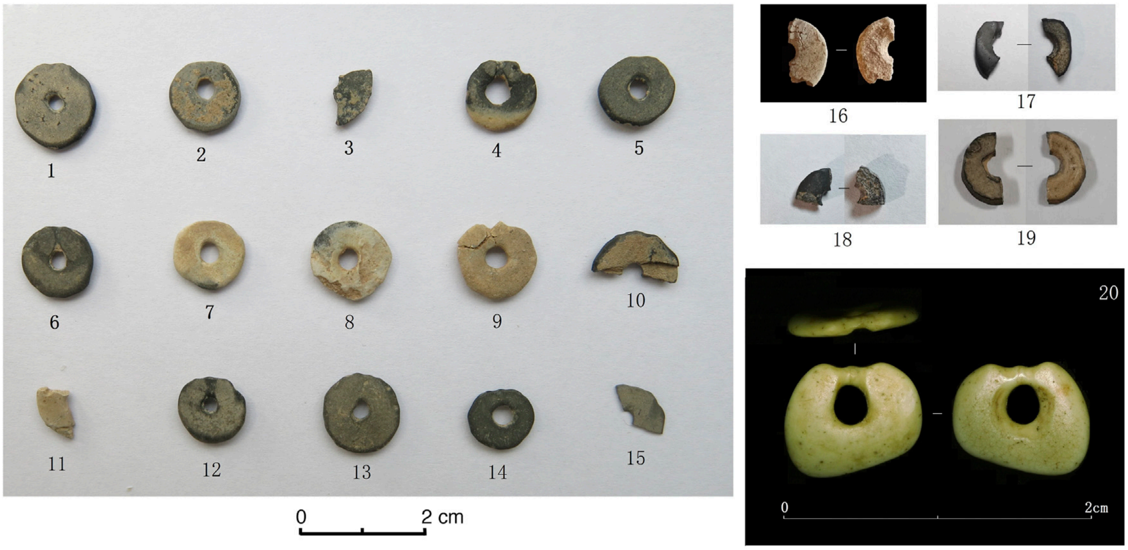

FIGURE 3 | Perforated OES pendants and pendant fragments from Shizitan SZT29 Layer 7 Spits 5-2 and SZT24. 1–19 are to the same 2 cm scale. 1–15. Pendants with usewear from SZT29 Layer 7 Spits 5–2, exterior surfaces; 16–19. Exterior surface **(left)** and interior surface **(right)** of pendants with use wear from SZT29 Layer 7 Spits 5-2; 20. SZT24, pendant top, exterior, and interior, showing heavy usewear. Scales are 2 cm in length.

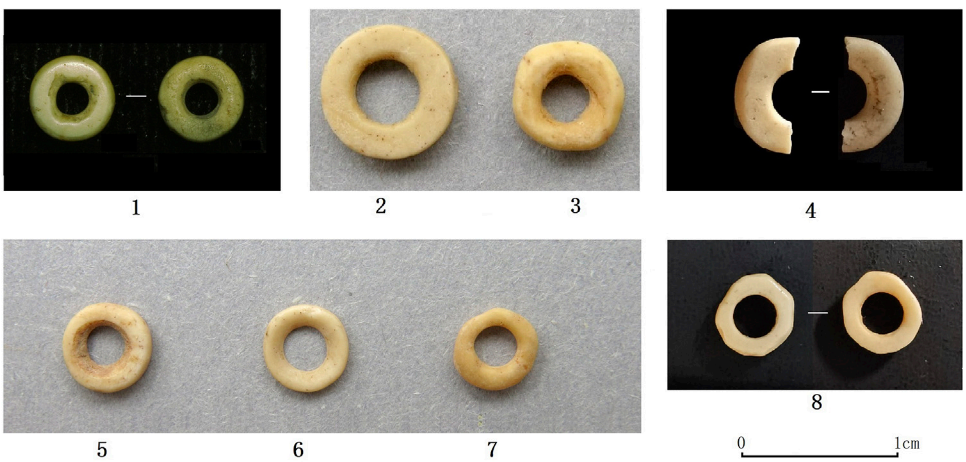

FIGURE 4 | Perforated OES beads from SZT29 Layer 7 Spits 2–1, SZT29 Layer 7 upper contact, SZT29 Layer 2, and SZT12G, all to the same scale. 1. Used bead from SZY12G (exterior and interior views); 2–3. Two used beads from SZT29 Layer 2 (exteriors); 4. Broken bead from SZT29 Layer 7 upper contact (exterior and interior); 5–8. Four used beads from SZT29 Layer 7 Spits 2–1: 5-6. Interior; 7. Exterior; 8. Exterior **(left)** and interior **(right)**.

half gray coloring is inferred to be indicative of burning, and some of these also feature surface crackling. However, the particular process by which they can become this color remains unknown despite actualistic studies. For example, Collins and Steele (2017) note that no experimental studies of heating using ovens or kilns has been able to reproduce black OES but suggest that oxygen availability and the introduction of organics need to be considered.

Those ornaments that show heavy usewear have an enlarged aperture diameter and lesser average thickness than those with no significant wear: this is also a phenomenon observed by Orton (2008: Figure 7), who attributes finding larger holes in finished beads than in unfinished ones to wear. One noteworthy form of wear on the Layer 7 Spits 5–2 ornaments is a pattern of abrasion on a particular part of the surface which previous studies indicate is the result of long-term usage of the ornaments as strung items (Song and Shi, 2013a; Song and Shi, 2013b). These studies determined that the abrasion patterns on the objects indicate that these early examples were worn as pendants (rather than beads strung together): this is ascertained by dark markings at the top of the pendant indicative of stringing being tied to suspend the ornament from the top (rather than from its center as a bead), and heavier wear at the bottom, outer surface (see Song and Shi, 2013a: Figure 3).

In SZT29 Layer 7 Spits 2–1, a total of 5 OES ornaments were unearthed. These ornaments show significant differences from the earlier examples. First, they are smaller in size than the ones from Layer 7 Spits 5–2. Their coloring is different, as well, being ivory in color and lacking indications of being burnt. In total, 4 of the 5 ornaments (**Figure 2**: 17–20; **Figure 4**: 5–8) are decidedly smaller in size but with a bigger hole: their average diameter is 5.52 (5.39–5.71) mm and the aperture diameter is 2.71 (2.60–2.88) mm. The larger drilling not only magnified the aperture diameter and decreased the average thickness to 1.23 (0.98–1.36) mm (**Table 2**) but also made these four ornaments somewhat irregular in shape, especially their outer contour, even though they were heavily polished all over. The fifth ornament (SZT29:72–96; **Figure 2**: 16; **Figure 4**: 4) from Layer 7 Spits 2–1 looks more circular, regular, and bigger than the other four beads, although the piece is partial, with a residual length of 7.57 mm. The clearly visible cross section features a very glossy hole wall with a very steep and polished edge, indicating that this was one of a string of beads. Ochre pigment residues were also visible on its surface.

SZT29 Layer 2 (ca. 19–18 Ka cal BP) marks the end of LGM conditions. In traditional morphological typological terms, the microblade technology had already shifted from semi-conical to boat-shaped microcores in the early spits of Layer 6, and these continued through Layer 2 (but see Song et al., 2019, for problems with the traditional lithics approach). Only two OES ornaments (**Figure 2**: 14, 15; **Figure 4**: 2, 3) were found in Layer 2 deposits: one (S29:1836; **Figure 2**: 14; **Figure 4**: 3) was excavated near a hearth, and the other was recovered through sieving of fill from the top of the layer. Compared to S29:72–96 from Layer 7 Top, the excavated Layer 2 ornament had a steeper and more polished hole wall but had a sub-regular round shape with the diameter 7.46, aperture diameter 2.89, and thickness of 2.01 mm; the sieved one was perfectly shaped into a regular, circular ring of diameter 8.74, aperture diameter 4.01, and thickness 1.7 mm (**Table 2**). Polish and ochre pigments could be observed on their surfaces.

Shizitan Locality 24

Locality 24 (36°2′12″N, 110°33′1″E) is located 1 km west of Gaolouhe Village. It was excavated in 2005. The 21 m^2 excavation area features ca. 0.5 m thick deposits covered by slope wash. About 1,000 lithic artifacts and animal bones, along with one OES bead, were unearthed. The site report has not been published. One AMS ^{14}C determination on animal bone is available, with a date of 20,460–19,960 cal BP (95.4%). The author SYH took part in the excavation and observed the OES bead (see Song and Shi, 2013a; Song and Shi, 2013b) (**Figure 2**: 13; **Figure 3**: 20). It measures 9.43 mm in diameter, 2.61 mm in aperture diameter, and 1.31 mm in thickness (**Table 2**). It shows indications of long-term usage, with abrasion and polish so heavy that its original shape could not be distinguished. However, due to this heavy usewear, we are able to determine that this ornament used the same stringing and tying fashion as the OES ornaments in SZT29 Layer 7 Spits 5–2 (**Figure 3**). Therefore, we can ascertain its usage as an originally ring-shaped pendant.

Shizitan Locality 1

Locality 1 (36°1′17.9″N, 110°31′7.11″E) is the westernmost and first excavated locality of the Shizitan site. It is located in fluvial deposits along the Qingshui River, 2 km southwest of Xialing Village, Jixian County. It was excavated in 1980, but methodology at that time simply divided the artifacts from all contexts into two periods, early and late (Linfen Administrative Bureau of Culture, 1989). Estimated dating ranges were 35.1–17 ka BP (Yuan et al., 1998; Xia et al., 2001). Two broken pieces of OES were unearthed together with 12 lithic artifacts with rough retouch. Observations of the OES surfaces revealed no signs of retouch or usewear, but there was apparent rounding at the shells' edges, which we attribute to fluvial transport.

Shizitan Locality 12G

Locality 12G (36°2′28″N, 110°33′6″E, 668 masl) is located 500 m west of Gaolouhe Village. It was excavated in 2005. The 6 m^2 excavation area features deposits 1.9 m deep. One radiocarbon date of ca. 15.5 Ka cal BP (**Table 1**), according to the dating laboratory, may be unreliable due to the condition of the bone sample: based on the artifact assemblage and geology of the deposits, we believe this locality dates later, roughly contemporaneous with SZT9 Layers 5 and 4. More than 1,700 artifacts were distributed throughout the deposits, including lithics, animal bone, and burnt bone (Shizitan Archaeological Team, 2013). The microblade technology can be characterized in traditional morphological terms by a single type of wedge-shaped microcore. Only one small, perforated OES ornament (S12G: 1853; **Figure 2**: 12; **Figure 4**: 1) was found and represents the artistic achievement of its time. This OES bead has usewear and is more regular in shape with a circular outline, center hole, and steep hole wall. It measures 5.57 mm in diameter, 2.12 mm in aperture diameter, and 2.13 mm in thickness (**Table 2**), which is smaller than those in SZT29 Layer 2 dating to ca.18 Ka cal BP.

Shizitan Locality 9

Locality 9 (36°02′44″N, 110°33′37″E, 688 ± 5 masl) is located about 150 m north of Gaolouhe Village in Jixian County. It was identified in 2000 and excavated over three seasons in 2001, 2002, and 2005 (Shizitan Archaeological Team, 2010; School of History and CultureShanxi University and Shanxi Provincial Institute of Archaeology, 2017). Nine AMS ^{14}C dates indicate the locality ranges across the YD and into the Early Holocene, which is the time period in the lowland North China Plain of the transition to sedentism, food production, and the Early Neolithic period (but not yet in the Loess Plateau). The excavated area reached 25 m^2 with deposits 4.55 m in depth composed primarily of aeolian loess. These can be divided into five cultural layers. A total of 2,359 screened artifacts and an additional 5,000 sieved pieces (primarily lithic artifacts and animal bones) were recovered from all layers except Layer 2. Burnt and broken animal bone indicates the general use of fire at locality 9 in all layers, and it is specifically indicated by a hearth in Layer 3. All of the examples of grinding stones, pigments, and ornaments made of mollusk shell and OES (Song et al., 2011; Song and Shi, 2013a; Song and Shi, 2013b) are found only in Layer 4, dating ca. 12,756–11,350 cal BP, which falls into the Younger Dryas period of climatic downturn (**Table 2**). A

FIGURE 5 | Perforated OES beads (top), preforms (rows 2, 3), and blanks (bottom row) from Shizitan SZT9. Row 1. Perforated pieces; Row 2. Bi-directionally drilled piece; Row 3. Uni-directionally drilled pieces; Row 4. Blanks or remnant pieces. Scale is 1 cm.

total of 11 pieces of OES were sieved from Layer 4. These include two perforated pieces (**Figure 2**: 1, 2; **Figure 5**: 1, 2), three pieces with uni-directional drilling (**Figure 2**: 4–6; **Figure 5**: 4–6), one piece with bi-directional drilling (**Figure 2**: 3; **Figure 5**: 3), and five blanks or remnant pieces (**Figure 2**: 7–11; **Figure 5**: 7–11). These allow understanding of the procedures for creating beads, from blank and preform preparation, to perforation or one- or two-sided drilling, to final finishing. Completed pieces average 4.05 mm in diameter, 1.23 mm in aperture diameter, and 2.08 mm in thickness (**Table 2**). The completed beads are not so regular in shape and have no usewear on their surfaces.

NON-EDIBLE EXPLOITATION AND UTILIZATION OF OSTRICH EGGSHELL

Ostrich eggs, as the largest of avian eggs, and with hard shells, can provide not only a high level of protein, fat, and calories (Collins and Steele, 2017) but also offer a raw material for non-edible products. Although whole ostrich eggs potentially could have served as a food source of great nutritional value, we have no direct evidence for the human consumption of ostrich eggs at Paleolithic sites in China. There are some reports of intact ostrich eggs being found *in situ* in northern China, but because they are still whole, they were never consumed or used by humans. Although it is difficult to ascertain if ostrich eggs had been used as a food source, generally speaking, ostrich eggs must not have signs of hatching if people acquired them for food. Hatched OES potentially leaves indicators on the exterior and interior surfaces that can be seen microscopically: the outer surface of an incubated eggshell will show fissures associated with the cuticle overlying the pore canals, and the interior surface can show dissolved mammillary cones (a calcium reservoir for embryo bone building) (Board, 1982; Dauphin et al., 2006; Wang et al., 2020). Nevertheless, good evidence for ostrich egg food consumption remains elusive.

Instead, we only have evidence of ostrich eggshell usage for non-edible purposes. In South Africa, in addition to OES personal ornamentation, OES water flasks with engraved designs are found, such as at Diepkloof Rock Shelter (Texier et al., 2013) in Middle Stone Age contexts as early as 60 ka BP. There are also other pieces with engraved geometric motifs dating possibly as early as ca. 109 ka BP. Other early, engraved OES with abstract designs are found in the Howiesons Poort Industry at Klipdrift Shelter, similarly dated ca. 66–59 ka BP (Henshilwood et al., 2014).

In China, evidence only exists for OES used as ornaments. Interestingly, observations of the OES ornaments at Shizitan indicate that in nearly all of the ornaments or by-production pieces (except those with heavy usewear that altered the surfaces), the dissolved tips of mammillary cones are visible on the interior sides. This indicates that for the Shizitan ornaments, hunter–gatherers were collecting shell from *hatched* ostrich eggs to manufacture the objects (**Figure 6**).

DIACHRONIC CHANGE IN THE UTILIZATION OF OES AT SHIZITAN

The Shizitan localities provide a localized record of diachronic change in OES ornament production and usage from the Last Glacial Maximum through Terminal Pleistocene. Controlled stratigraphic excavations with radiocarbon dated sequences allow us to place changes in the OES ornament typology and hypothesized function into changing environmental and cultural/technological contexts, leading to insights into the potential roles these objects played. We can divide the diachronic changes in the production and usage of OES ornaments at Shizitan into four phases.

Phase 1 is found in Layer 7 Spits 5–2 at Shizitan 29 and would date to an earlier part of the date range of ca. 26–24 Ka cal BP for Layer 7. The earliest OES ornaments at the site appear as pendants in this layer, as is determined by usewear from them being individually tied with a string through the hole and wrapping one perimeter edge at what then becomes the pendant's top (Song and Shi, 2013a; Song and Shi, 2013b). A total of 19 perforated OES ornaments are identified for this phase. These early pendants are larger than all subsequent OES ornaments: they are bigger in average diameter (11.46 mm) and have a smaller average aperture diameter (2.85 mm). This means that the display area of the surface of the ornaments is much greater than in later periods. Here (see **Table 2**), we compare the display area using the ratio of the "body width" (meaning the measurement from the hole wall to the outer edge) of the beads to the "aperture diameter" (BW/AD) to express the display area, which for 11 ornaments in Layer 7 Spits 5–2 averages 1.57 (subsequent phases range 0.51–1.15). The larger size and large display area of the earliest OES ornaments are visualized in

FIGURE 6 | Interior surfaces of OES fragments from Shizitan 9 Layer 4 at ×500 magnification. **(A)**. Undrilled fragment recovered by sieving. **(B)**. Fragment with drilling from one side, recovered by sieving. **(C)**. Piece drilled from two sides that was shaped into an irregular circular ornament; recovered by sieving. **(A, B)** show dissolved tips of mammillary cones and exposed pore canals indicative of humans at Shizitan acquiring OES raw material from eggs that had incubated and hatched. On **(C)**, parallel striations are visible indicating that completed beads are polished during a final step in their manufacture, and this obscures the mammillary cones.

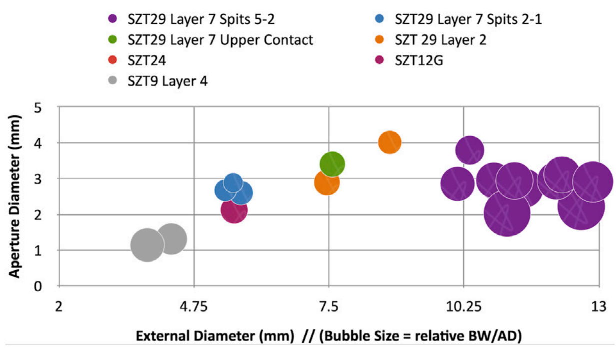

FIGURE 7 | Bubble chart plotting three variables to visually compare Shizitan OES ornament data: external diameter (mm; x-axis), aperture diameter (mm; y-axis), and the relative "display area" (body width/aperture diameter ratio), indicated by the size of the bubble. Colors indicate Shizitan contexts. Plotted ornaments must have all three values available; see **Table 2** for values. Note the large display area (bubble size) despite the small external diameter for the latest (Phase 4) ornaments, from SZT 9.

the bubble chart in **Figure 7**. Also it is noted that unlike later ornaments, the Phase 1 OES pendants are seemingly burnt, as indicated by gray and/or black coloration, although the heating process that may turn OES this coloration remains unknown (Collins and Steele 2017). They are finished products with signs of use. Their appearance in Layer 7 Spits 5–2 means they are present at the site before microblade technology is fully established (Song et al., 2019).

Shizitan 29 Layer 7 Spits 2–1 represents Phase 2, which would date to the later stage of the date range ca. 26–24 Ka cal BP. Phase 2 is represented by a new type of OES ornament (beads), smaller in size than the Phase 1 pendants. Four small OES beads were recovered from sieving of excavated fill from around a series of hearths in the Layer 7 spits 2–1. Although the four beads are from contexts scattered around the hearths, the beads bore no signs of purposeful coloration change. Interestingly, the Phase 2 change to beads is also when microblade technology is established at the site (Song et al., 2019). In some examples, over-drilling has removed the natural outer or inner surface of the OES because the external diameter of the hole reaches the full diameter of the bead on one side. This may mean that an objective in these beads' production was to systematically create beads with regularity in size and section shape (rather than with a shiny, natural surface). The four beads have nearly the same diameter, aperture diameter, and thickness. This uniform size could be an indication that they would be strung in linkage to each other, as beads. Also noteworthy is that they have the smallest BW/AD ratio of 0.51, but the average aperture diameter of 2.71 mm is not much bigger than the ornaments from Phase 1 (these values are visualized together in the **Figure 7** bubble chart).

Phase 3 (ca. 24–16 Ka cal BP) is represented by the use of stylistically larger and heavier-looking OES beads and the use of OES again for pendants. The single pendant from Shizitan 24 shows no great change in size and shape from that of Phase 1, but it does show serious attrition into an irregular quadrangular shape with two very deep striations from strand-wear on the top. The excessive attrition of the original dimensions of the piece renders measurement meaningless. We interpret Phase 3 as a technical extension in pendant manufacture and use from Phase 1 (potentially a continuous tradition but not found at limited Phase 2 excavated localities).

Beads continue to be used in Phase 3 but with some stylistic change. Four OES beads are identified. The earliest one was found in the upper contact of cultural Layer 7 at Shizitan 29 so would perhaps date ca. 24 Ka cal BP. Other examples are found 6,000 years later in Layer 2 in Shizitan 29 and another 2,000 years after that in Shizitan 12G. Even though the measurement of the bead in SZT12G is nearly the same as that in Phase 2, it and the other beads in Phase 3 look bigger and heavier. This appearance is brought about by technical developments and a maturation of techniques oriented toward better visual effect, including smoothing of the surface, rounding of the shapes, and drilling steeper inner walls for the holes. Also noticeable is that the BW/AD ratio increases from 0.62 to 0.8, meaning that the bead hole was becoming relatively smaller and smaller. In addition, pigments can be observed on the beads with the naked eye, especially on the OES interior side, even though the beads had already been rounded through wearing.

During the last phase, Phase 4 (ca. 12.8–11.4 Ka cal BP), eleven OES pieces from Shizitan 9 Layer 4 allow us to observe the local technological process of bead manufacturing. Two of the pieces are completed beads with drilled apertures, while three uni-directionally and one bi-directionally drilled preforms were also recovered, along with five pieces that could be blanks (**Figure 5**); for further discussion of identifying drilling technology, see (Song and Shi, 2013a; Song and Shi, 2013b; Song et al., 2011). The finished beads in Phase 4 are much smaller not only in diameter (3.8 and 4.29 mm) but also in aperture diameter (1.14 and 1.31 mm) (**Figure 7**). Their small external diameter of <5 mm falls into Orton's (2008) range of "small beads." The small aperture raises the BW/AD ratio to 1.15. Song et al. (2011: Figure 5) observe that the aperture diameters of the drilled OES pieces match the size and usewear patterns microscopically observed on recovered microblade pieces that could have served as drilling bits. Concurrent technological improvements in ornament production can also be seen in the perforated shell ornaments from Shizitan 9, for which Song et al. (2011) argue the angle of the hole sections is resultant from microblade drills. These changes correlate with the onset of the climatic downturn of the Younger Dryas. The bead-making record at Shizitan ends at this point. A final stage may be represented by the Shuidonggou site. The Shuiddonggou region was abandoned at the LGM, with human groups not returning until the early Holocene, ca. 10.5 Ka cal BP (Li et al., 2019), when migrating hunter–gatherer groups brought microblade technology and OES bead-making with them: examination of OES beads at Shuidonggou 12 indicates multiple drilling techniques, including twisting drilling and multi-rotary drilling with different kinds of drill bits (Yang et al., 2016).

DISCUSSION

A Shift to Local Ornament-Making

Microscopic examination of the thickness and structure of the OES unearthed at Shizitan indicates that the eggs belong to the most recent but extinct species of North Asian giant ostriches, *Struthio anderssoni* (Lowe, 1931; Yang and Sun, 1960; Zhao et al., 1981; Janz et al., 2009; Song and Shi, 2013a; Song and Shi, 2013b; Yang et al., 2016), which in the Late Pleistocene had a small population distributed across a wide geographical range over the Malan Loess along the Taihang and Zhongtiao Mountain chains in Shanxi, Hebei, and Henan provinces in North China (Young, 1933; An, 1964; Chen, 1985). Although the OES from Layer 7 of Shizitan 29 has a smaller average thickness of 1.86 mm than *S. anderssoni*, it is also smaller than the 1.9 mm average thickness of OES for the smaller, living ostrich, *Struthio camelus* (Lowe, 1931); this is because the shell thickness was reduced due to excessive use and polishing of the surfaces, especially the exterior surface. Some pendants, however, preserve a thickness up to 2.29 mm.

Ornaments in Phases 1–3 are found in a completed stage of manufacture and have signs of heavy usage. We hypothesize that this indicates that these ornaments were manufactured elsewhere. Manufacturing stages generally include blank preparation (cutting), perforating/drilling, trimming, and grinding (see Orton, 2008; Werner and Miller, 2018). During Phase 4, however, the assemblages contain broken pieces or blanks, and non-completed preforms with drilling holes on one or both sides: these can be identified as by-products, abandoned pieces, and other indicators of manufacture on site. This could mean a shift to local production, where Shizitan inhabitants may have carried out all stages of the process, from collecting OES, transporting OES fragments and blanks with them (or storing them at what would become a site favored for OES ornament production), and manufacturing the ornament products locally when and where they were needed. It is only from Phase 4, around 12 Ka cal BP, that we have these indicators of localized ornament-making, and this raises new questions about other changes that might be occurring in site occupation and activities at Shizitan 9 during the YD.

From where the OES raw material originated—local or distant—is another important but still unanswerable question. Although it is difficult to know how the hunter–gatherers of Shizitan acquired OES, because of the presence of blanks in Phase 4, for this stage, it can be hypothesized that they collected broken OES pieces within the range of their mobility (Song and Shi, 2013a; Song and Shi, 2013b). In Phases 1–3, no evidence of Shizitan area production has been found nor is there evidence anywhere else in the wider region: there are only finished ornaments, so we hypothesize that they could have been manufactured elsewhere. OES raw material apparently was not abundant in the Shizitan region as no pieces of OES are ever found in non-cultural sediments nor were found over 10 years of field investigations across the region. Their scarcity and perhaps more distant sourcing is also hinted at by the lack of evidence at the sites of ostrich eggs serving as a food resource since observation of the interior OES surfaces indicates that the eggshell present at the sites had been incubated and hatched. This would mean OES is present at sites only because finished ornaments were brought to the site or because limited numbers of pieces of OES were brought to the site to be made into ornaments.

Standardization and Size Reduction of Ornaments With the Improvement of Drilling Technology

The OES productions at Shizitan can be classified into pendants and beads according to how the ornaments would have been strung or suspended, or, in other terms, how they would have been displayed. As mentioned above, pendants are those ornaments individually suspended from a knot at what becomes the top orientation of the ornament (Song and Shi, 2013a). Such pendants could have been worn on the body or attached to garments or other items. The mode of stringing and suspension for pendants emphasizes the display of their broader surfaces (front or back, or what was the exterior or interior surface of the OES), and these pendants typically have a glossy surface for such display purposes. Furthermore, the BW/AD ratio, discussed above, is much larger for pendants (=1.57), reflecting the objective of producing a larger display of the shell surface. Bead production had different objectives that emphasize uniformity and the rhythm of beads strung together with each other, rather than a larger relative display surface of an individual bead.

The diachronic view afforded by the Shizitan localities shows that pendants and beads are not just typologically (formally) distinct but are manufactured and favored in distinct time periods through relatively independent systems of production with different objectives related to differing purposes of the ornaments' display.

Pendants appear first, when core and flake assemblages still comprise the lithic technological record at Shizitan. Although there is a gap in the record after 24 Ka cal BP for pendants (which is also after microblades appear), they are last present just after ca. 20 Ka cal BP. Beads first appear, in a completed form, in the Shizitan record during the LGM, contemporaneous with the appearance of the early microblade industry in SZT29 Layer 7 Spits 2–1, and then, beads persist and prevail in the record from 24 Ka cal BP onward through the Terminal Pleistocene. However, evidence for possible local production at Shizitan appears only in Phase 4, correlating with the Younger Dryas, in Shizitan 9 Level 4. The beads from this level are remarkably smaller in size (average diameter = 4.05) than earlier beads. This may be due to changing styles and tastes, to changing modes of stringing or affixing beads, and/or possibly to greater scarcity of the OES raw material during the YD. The fact that this change occurs within the context of the climatic and environmental downturn of the YD, along with potential changes in animal (Song et al., 2017; Zhang et al., 2019) and plant (Liu et al., 2011) exploitation patterns, as well as what our preliminary research indicates might be technical changes in microblade production at Shizitan 9, should also be considered.

Technical changes in the manufacturing process of the OES ornaments can also be observed, as has been studied for the drilling processes for OES at Shuidonggou (Yang et al., 2016; Wei et al., 2017) and for mollusk shell ornaments from SZT9, 12A, and 29 (Song et al., 2011). Two interrelated trends are noted that had to be accompanied by technological developments in drilling: these result in the gradual increase in BW/AD accompanied by, or resultant from, the decreasing bead aperture diameter (even as the bead diameter itself was greatly decreased in Phase 4). The earliest beads at Shuidonggou and Shizitan were likely made with flake-tool drillers as microblade technology was not yet available. The later production of smaller bead holes benefited from better drilling tools, which likely used drill bits made of microblades (Song et al., 2011). Although dating to the Early Holocene, slightly later than SZT9, this has also been shown by microscopic analysis, usewear, and experimental studies at Shuidonggou Locality 12 (Yang et al., 2016). The objective of drilling holes of smaller diameter would relate to changes in the modes of stringing and in the desired type of suspension of the ornaments. Smaller holes can imply the use of thinner strands and thus perhaps changes in techniques for producing string from the plant fiber (e.g., see Hardy, 2008) or changes in the preparation and use of animal fibers, such as sinew, hair, or wool. We hypothesize that the smaller hole (and the more standardized bead size) was directed toward concerns for stringing beads together to give a uniform appearance and for them to be more steadily threaded on the string, which would have been close in thickness to the beads' AD. This objective was met by the observed greater standardization in the production of the ornament size and shape, improvements in the drilling technology to produce smaller holes, and perhaps by (unobserved) improvements in producing appropriate fibers for stringing.

The clear reduction in size of OES ornaments is the most noteworthy change through time, and this needs to be considered further. The average diameter of Phase 4 beads (4.05 mm) are 27% smaller than the next smallest beads, from Shizitan 12G in Phase 3. Although we cannot determine the reasons for the decreasing size, in addition to the changing environment, economy, and technology mentioned above, potential changes in site functions and hunter–gatherer social organization and social networks would correlate with the changes in the bead size as well. For Shuidonggou 2, Wei et al. (2017) note that because smaller OES beads require greater investment of time and effort to manufacture and more specialized skills, and because their processing involves greater risk of failure than larger ornaments, in embodying these differences, the meanings that smaller beads may signal could be different; they also cite ethnographic examples of African groups in market economies reserving smaller beads for themselves while selling larger beads. We note an archaeological example, from southern Africa, of changes in OES bead size that accompanied changes in regional economies and competition between herder and hunter–gatherer groups. After herding arrived in the region at 2000 BP, OES beads at subsequent herder sites were always larger than those associated with forager sites, even though regional differences in bead size were subtle, on the order of millimeters (Jacobson, 1987a; Jacobson, 1987b; Smith et al., 1991; Sadr et al., 2003; Wilmsen, 2015; Miller and Sawchuk, 2019). The trends at Shizitan deserve further investigation into their relationships with changes in economy, social organization, cultural communication, and ideology, or even the movements of new populations into the region. While OES ornament size reduces by the time period at Shizitan, at Shuidonggou at ca. 30,000 years ago, Wei et al. (2017) argue that the differing bead sizes and types are found within a narrow-enough time range that the differences in beads in the cultural layer are resultant from the presence of different human groups with unique types of beads at the site.

Changes in OES Ornament Color Modification

As shown in **Figure 3**, the pendants in Phase 1 were all black or gray in color. Such coloration can be a result of heat treatment (intentional) or burning (unintentional) but possibly could result from post-depositional taphonomic processes that have not been identified. Heat treatment of the ornament material is an intentional activity by the ornament makers done to enhance the visual impact of the ornament or to allow the ornament to convey meaning through the special colors produced, and to alter the material's physical properties for workability (e.g., Godfrey-Smith and Ilani, 2004; d'Errico et al., 2010; Salomon et al., 2012).

FIGURE 8 | OES boiling experiment. The image shows a piece of OES that had been partially suspended in boiling water. The color change of the submerged part (top), followed by the color transition at the water line, can be seen.

This is supported by examples in modern bead-working (Schoeman, 1983; Wickler and Seibt, 1995). The natural color of the OES is light yellow to white, but the coloration of archaeological OES ornaments, such as some at Shizitan, can be altered. It can be difficult to ascertain if such color modification of the OES was intentional or not. Perhaps natural coloration was not preferred by the earlier Shizitan bead makers (but was by the later ones), and so they intentionally burned the OES to turn it black or gray. However, unintentional burning or post-manufacturing taphonomic processes could have altered the color of the OES. OES heating experiments by Craig et al. (2020) demonstrate that while furnace heating to 200, 350, 550, and 700°C can produce colors found archaeologically, physical changes in the OES from 350°C make the material subject to easier breakage during working. Colors produced by Craig et al. (2020), Collins and Steele (2017), and Texier et al. (2013) in the 200–350°C range include hues of yellow, orange, reds, and brown, but grays appear only above 350°C, and typically in the higher temperature ranges that increase the breakability of the OES. This favors an explanation of the Phase 1 OES as having unintentional color modification.

While these experimental studies of OES color change have focused on fire as the heat source in an open-air environment, here we present one preliminary test to see if boiling would also alter color. One author (YHS) partially suspended a piece of OES in boiling water. One-time boiling resulted in multiple colors: the coloration near the water surface line transitions from yellow to red for the submerged part (**Figure 8**). Further controlled experimental studies of heat changes are planned.

We also note other evidence that needs to be considered in assessing intentionality of color modification. First, color change also can be found combined with bright polishing, which if intentional rather than from usewear, was performed to produce beautifying surface effects. One OES bead at Shuidonggou 2 (SDG2: 6500) had been heat-treated after manufacture to turn it black but has usewear from after the bead had been treated (Wei et al., 2017). Second, there are also parallel examples of heating of other materials. Marine mollusk shell pendants with a drilled hole in the top were also burnt to a black color (Song and Shi, 2013b: Figure 13), but these could have been subjected to the same processes, intentional or unintentional/post-manufacturing, as the OES pendants. One line of evidence, however, allows us to argue for some forms of intentional heat treatment being present from the time period of Layer 7 Spits 2–1. Microblades appear in these spits, and preliminary studies indicate that Shizitan 29 knappers employed heat treatment on the flint they used as a necessary step in the production process that facilitates the removal of the microblades by the pressure technique (Song et al., 2019). They, thus, had knowledge of the potential for heat to alter the physical qualities of materials for technical advantage. We should still ask, then, if in the same way, ornament makers were able to control OES color modification.

Modification of OES color through heating, burning, or post-depositional processes is not seen after SZT29 Layer 7 Spits 5–2, with one exception, a burnt OES piece with a half-completed hole drilled from one surface found in SZT 9 Layer 4: this piece was abandoned after drilling failure and was discarded into a hearth with other animal bones, so its color modification was unintentional.

It is noteworthy that all of the ornaments in Shizitan Layer 7 Spits 5–2 were burnt, but we found no hearths in these spits. In layers where hearths are found, to the contrary, all of the OES ornaments around the hearths still maintained their natural, ivory color, showing no signs of color modification through heating (with the one exception from SZT 9).

Ochre

Although heat treatment may not have been applied for color modification, coloration of ornaments was still carried out at Shizitan using red ochre, which is found in SZT29 Layer 7 Spits 2–1 and onward. Excavated examples include two ochre pieces with ground facets, one from Layer 7 Spits 1–2 (**Figure 9**: 2) and the other from SZT9 Layer 4 (**Figure 9**: 1). Clear parallel striations from grinding are observed on 2–3 ground facets of each piece of the ore. Also, traces of the ochre on grinding slabs (**Figure 9**: 3, 5) and handstones (**Figure 9**: 4) show that humans may have smashed the ochre to grind the smaller pieces into pigment powder. Such pigments are observed on the surfaces of the naturally colored OES (e.g., on the inner surface of a bead from SZT29 Layer 2) (**Figure 9**: 6), and they have remained attached even after usage (apparent usewear) and post-depositional processes. No such pigments are observed on the black/gray pendants from SZT29 Layer 7 Spits 5–2 nor were ochre pieces found associated in these deposits.

A grinding slab from Shizitan 9 Layer 4 had microscopic residues of hematite ochre in addition to evidence for processing a broad range wild plant foods (Liu et al., 2011), and the slab was associated with ochre ore fragments, two of which had striations (Shizitan Archaeological Team, 2010). A second grinding slab from the same level had similar usewear patterns to abrading mollusk shell and stone (Liu et al., 2011), leading us to conjecture their usage during processing of OES ornaments, as observed on

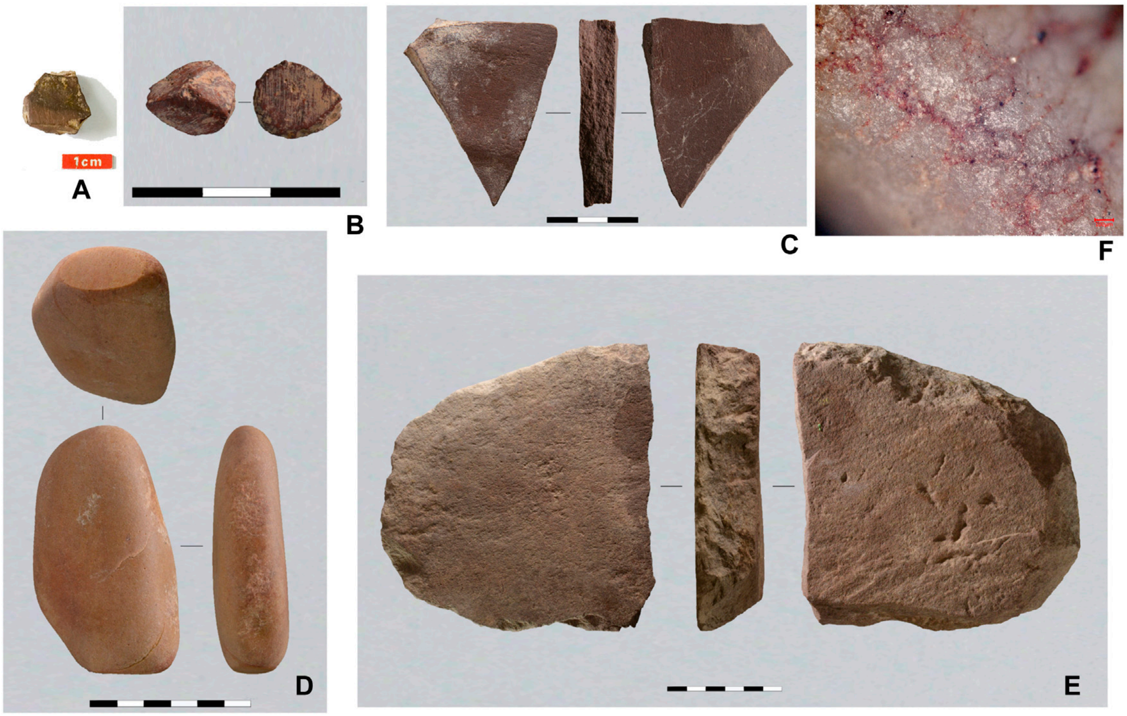

FIGURE 9 | (A). Ochre (S9:370) from SZT9 Layer 4; **(B)**. Ochre (S29:60–103) from SZT29 Layer 7 Spits 2–1; **(C, E)**. Grinding slabs (S29:66–109 and S29:13110) from SZT29 Layer 7 Spits 2–1 with traces of ochre; **(D)**. Handstone (S29:11,959) from SZT29 Layer 7 Spits 2–1; **(F)**. Ochre pigment on the inner surface of a bead from SZT29 Layer 2.

Shuidonggou beads (Wei et al., 2017). These slabs and the coloring of OES beads with hematite ochre during Phase 4 indicate another aspect of the complete production process carried out on site in this stage and is another significant aspect of bead production and usage at Shizitan during the YD. The question should be raised if this relates to new forms of social signaling being required during this time period of likely increased stress and social competition. However, as mentioned above, ochre compounds on OES ornaments are found 19,000 years earlier at Shuidonggou 2 (Pitarch Marti et al., 2017), perhaps significantly at a time when "indigenous" advanced core and flake industries are replacing an "intrusive" blade industry (see Li et al., 2019).

CONCLUSION

Ostrich eggshell ornaments are infrequent discoveries in Late Paleolithic sites in North China. While their archaeological rarity may reflect their fragility and difficulty to be preserved and recovered, it is also a true reflection of the low amounts available in the Paleolithic period. When combined with their aesthetic qualities, their rarity also produces their value over other materials in serving in symbolic and social signaling roles that we only understand abstractly. The 41 OES items recovered at the Shizitan site localities, with well-dated stratigraphic proveniences and rich, associated material culture, provide us a rare opportunity to understand the diachronic changes in the non-edible utilization of this animal resource over time, particularly technological and typological developments that reflect changing human objectives in manufacturing and usage (as ornaments). These changes may relate to changes in hunter–gatherer lifestyle and activities at sites through the major climatic and environmental changes from 28–11 Ka cal BP, including the LGM, amelioration, and the YD. We divide OES ornament usage into four distinct phases during this time range and are able to note a number of significant changes through these phases, including the change from importing finished ornaments to local manufacture; typological changes from pendants to beads; changes in size preferences from ornaments, to larger-sized beads, to small beads; changes in the drilling technology, such as from flake-driller to microblade-driller; and changing preferences in color modification, including heating/burning and coloring using red ochre pigments. These all provide insights into potential roles that OES ornaments may have played and changing meanings of these objects among the Shizitan hunter–gatherer groups in different time periods.

OES ornaments, thus, provide another pathway to understanding the expression of behavioral modernity and an "Upper Paleolithic Revolution" in Late Paleolithic North China (Bar-Yosef, 2002; Bar-Yosef, 2007; Norton and Jin, 2009). They reflect visual signaling on a small scale (beadwork or pendants) using a rare animal resource (ostrich eggs). We also note that this usage of OES excludes the egg's potential role in nutrition and may be an indicator of the low availability of the ostrich shell within the usual range of mobility of Shizitan's inhabitants: as with the marine mollusk shell at the site, OES may represent broader social networks and exchange. Further comparison on a larger scale of objects and materials such as OES and marine shell is worth carrying out to shed further light on the nature of communication amongst hunter–gatherer groups in North China through the Last Glacial period, and this should also have repercussions for reconstructing broader patterns of mobility and migration of modern human populations across northeastern Asia and into the Americas.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

JS directed the excavations of the localities of the Shizitan site. Project administration was carried out by YS and JS. Funding acquisition was carried out by YS and DC. Conceptualization was performed by YS and JS. Laboratory analyses of the ornaments and experimental studies were conducted by YS. Methodology was performed by YS and JS. Formal analysis was carried out by YS and JS. Visualization and investigation was performed by YS, JS, and DC. Original draft was written by YS and DC. Review and editing was performed by DC and YS.

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